ELECTRIFICATION OF I. C. R. R. TERMINAL

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ARMOUR INSTITUTE OF TECHNOLOGY

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ELECTRIFICATION OF ILLINOIS CENTRAL RAILROAD TERMINAL

A THESIS

PRESENTED BY

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PREFACE

The work contained herein is intended to determine only those engineering features which have a direct bearing on the economic construction and operation of the road. To fix upon the final details of the entire project, while seeking the answer set forth in the statement of the problem, would entail an amount of time and labor wholly unnecessary and unjustifiable in view of the small additional accuracy that would be attained thereby.

The authors have attempted to clearly set forth their method of arriving at all conclusions, and in each case they have stated the reasons for their final selection.

The question of motor selection was made the subject of a rigid and thorough investigation, because the selection of motor, gear ratio, and control equipment forms the basis of all calculations, relating to the generation, transmission, and distribution of energy

to the cars. Small changes in gear ratio or control equipment not only effect the size and capacity of all equipment in the system back of the motors, but materially effect the cost of operation.

The authors take this opportunity to thank Mr.J.G.Brumley, Chief Corporate Engineer, Illinois Central Railroad, through whose efforts they obtained valuable data regarding grades, service, and steam road equipment of the Illinois Central Railroad.

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PRELIMINARY

Electrification of the entire service of the Illinois Central Railroad inside the limits of Chicago is provided for in an ordinance considered by the members of the city council's committee on railway terminals. Electrification is only one feature of the ordinance. It provides for the expenditure of millions of dollars for improvements, including a new $20,000,000 passenger station at Twelfth Street, large enough to take care of every passenger train that does not use the Chicago & Northwestern and Union railway stations. The new measure means a tremendous step toward the solution of Chicago's railway terminal tangle, the doing away with the smoke muisance in Grant Park, and the throwing open to the public of the entire lake shore. Under the new proposed plans, which differ materially from the ordinance that was under consideration several years ago, though many features were retained, a new harbor district is

created; the city gets air rights over the Illinois Central Railway, enabling street cars to reach the new Field Museum; there will be a new suburban station passenger station at Randolph Street, and a subway loop and there will be seven viaducts and a subway between the river and East Forty-Seventh Street. For economical reasons the electrification will extend beyohd the city limits to Matteson, the end of the suburban system and 28 miles from the Randolph street station.

Electrification is provided for through periods of years. The first step will be the electrification of the entire suburban service. During the next period the road will electrify all its freight service north of Twelfth Street. During the third period all the freight service between Twelfth Street and the city limits will be electrified and all through passenger service will be taken care of in the fourth period. After

the second period there will be no more steam trains north of Twelfth Street.

EXTENT OF PLAN OF ELECTRIFICATION

The plan presented by the Chicago Association of Commerce in 1912 provides for the electric equipment and operation of all railroad tracks within the city of Chicago. It cannot be assumed that the boundary of the city is in all cases a strategic point to be observed for such a purpose. A railroad having important suburban passenger service originating beyondthe city limits, if required to electrify to the city limits, might for the greater convenience of its patrons be justified in continuing its scheme of electrification to some more distant point.

Complete electrification within the city presupposes the removal to some point outside the city of all steam locomotive terminals, with their accessory facilities, such as coaling stations, water tanks and cinder pits, which are now located in the city. The facilities to be established outside the city for the care of steam locomo-

tives, and the tracks necessary to accomodate trains while the motive power is being changed from steam to electric or from electric to steam, all involves the building of a considerable establishment. In the case of some railroads it seems impracticable to obtain space at the city limits in which to develop these necessary transfer facilities and, as a consequence a more distant point has been accepted. The outer limits of complete electrification have, therefore, been fixed substantially upon the basis of the following consideration:

1. In the case of each railroad, it has been sought to terminate complete electrification at the first satisfactory point beyond the limits of the city.
2. In the case of railroads having large yards, repair shops or other facilities outside of the city and within a short distance therefrom, the location of such facilities has been accepted as a reasonable terminus for complete electrification.

The terminus of the Illinois Central Railroad is Matteson, Illinois, which is 28

miles from Chicago. At this terminus is the large classification yard, Markham Yard.

PROVISIONS FOR MULTIPLE - UNIT SERVICE

It is assumed that all passenger service which is conducted wholly within the limits of electrification is to be performed by multiple-unit equipment, and provision made for the care of such equipment is to be made accordingly. It is not contemplated that multiple-unit equipment will ordinarily be used in any other service. Passenger service which extends beyond the limits of electrification is to be performed by electric locomotives when inside the limits and by steam locomotives when outside. Under this principle multiple-unit service is not reserved for conditions of congested traffic. In working out the details under this plan multiple-unit equipment will be used by the Illinois Central Railroad in their suburban service between the Randolph Street Station and Matteson including also the South Chicago

and Blue Island branches.

The foregoing provisions involve existing trackage of the Illinois Central Railroad is shown in the following:

	MILES	
Route embraced by complete electrification	33.5	
Route embraced by partial electrification	13.7	
Total route		47.2
Main track	168.94	
Other track	163.89	
Adjacent industrial track	4.18	
Total electrically equipped track		337.01

ROLLING STOCK

Suburban

There are now in use 44 locomotives of the rear tank type built especially for suburban service. The various classes and certain items concerning each are shown below in Table (I).

The side door cars are strongly built. a complete steel underframing is provided composed of four longitudinal, 9 in., 21-lb. I beams tied together with 6-7 in., 15-lb. I beams between two end sills of 9 in., 25-lb. Channel. Diagonal bracing and gusset plates are used at corners and at body bolster support. The floor is 1/4 in. deck plates riveted directly to underframing. The superstructure is semi-steel construction. The side doors are operated by compressed air and an electric signal circuit is arranged so that when all doors on train are closed, the fact is instantly communicated to the engineer. These cars have been in use about

15 years and have given good satisfaction in handling crowds. The cars are necessarily heavy on account of the necessity of furnishing all supporting strength in the underframing, it being impossible to frame around the side doors.

Typical Suburban Data

From data secured from the Illinois Central Railroad Company, the locomotives weigh from 53.8 tons to 99.9 tons; the coaches weigh from 17 tons to 41.4 tons. The heaviest train pulled is 249.9 tons. This includes the weight of the locomotive and tender which weighs 99.9 tons. The lightest train pulled is 100 tons. This includes the locomotive and tender which weighs 53.8 tons.

Table (II) gives the average train length and weight from seven sheets of information obtained from the I.C.R.R.

TABLE I

CONDENSED SPECIFICATIONS - I.C.R.R. SUBURBAN LOCOMOTIVES

TYPE	2-4-4	2-4-6	2-6-4	4-6-6
No. in use	21	10	2	7
Cylinder Dimensions	16x22	17x24	18x22	18x24
Driving Wheel Diameter	56-1/2"	56-1/2"	56-1/2"	56-1/2"
Wheel Base	32' 7"	32'7"	33'5"	34'3"
Total Wt. in tons	59	83	80	68
Wt on Drivers	28	36	46	31
Tractive power 20% adhesion	11,200	15,400	17,200	12,400

TABLE IA.

THE CLASSES OF SUBURBAN COACHES

	Multiple Side Door	Standard End Door
Length over all, ft.	71	51
" " end sills	64	45
Width over sheathing	10' 5"	8' 5"
Weight of Body	61,400	25,400
" " trucks	21,400	16,200
Total weight	82,800	41,600
Seating capacity	100	56

TABLE II

Sheet	Average No. of cars per sheet	Average Total Wt. per sheet
1	4.5	174
2	4.5	162
3	4.4	157
4	4.8	163
5	4.9	187
6	4.1	164
7	3	175

The maximum number of cars per train is six and the minimum is two.

Through Passenger

Table (III) is a list of the different types of locomotives, their weights, tractive effort, number of each, classification, etc.

Typical Passenger Trains

The heaviest trains pulled out of 12th Street are around 1000 to 1100 tons. The three heaviest are

1st A train consisting of 12 coaches and locomotive weighing 1064.1 tons. The locomotive weighs 231.7 tons and the 12 coaches 832.4 tons. Assuming 30 tons for passengers

and 20 tons for baggage the total weight of the train loaded is 1114.1 tons.

2nd A train consisting of 12 coaches and locomotive weighing 1110.9 tons. The locomotive weighs 217.1 tons and the 12 coaches 993.8 tons. Assuming 30 tons for passengers and 20 tons for baggage the total weight of train loaded is 1160.9 tons.

3rd A train consisting of 13 coaches and locomotive weighing 1005.1 tons. The locomotive weighs 217.1 tons and the 13 coaches 788 tons. Assuming 30 tons for passengers and 20 tons for baggage the total weight of the train loaded is 1055.1 tons. Other through passenger trains vary from 340 tons to 1100 tons.

Table (IV) shows the maximum daily through passenger traffic in and out of 12th Street.

Switching

Table (V) is a list of the different

TABLE III

NO. IN SERIES	WEIGHT OF ENGINE LBS.	TRACTIVE EFFORT	CLASSIFICATION
1	231,750	30,551	Pacific Passenger
8	245,000	33,150	"
4	235,000	29,920	"
5	278,000	40,758	"
3	149,700	21,922	10-Wheel Passenger
1	115,800	19,475	"
1	120,000	23,826	"
1	92,260	17,704	"
7	119,700	15,422	8-Wheel Passenger

TABLE IV

STATEMENT SHOWING MAXIMUM DAILY THROUGH PASSENGER TRAFFIC IN AND OUT OF 12TH ST.

Direction of Travel	No. of Trains,	Cars	Cars per Train Max.	Min.	Av.	Tonnage Cars,	Engine and Tender	Total
Inbound	33	284	19	3	9	17,213	7,015	24,228
Outbound	30	242	13	4	8	15,290	6,371	21,661
TOTAL	63	526	19	3	8	32,503	13,386	45,889

TABLE V

No. in Service	Weight of Engiue, Lbs.	Tractive Effort, Lbs.	Class
6	142,000	31,287	Wheel Switch
5	118,900	25,811	"
21	84,000	19,440	"
10	166,000	32,487	"
24	169,000	34,398	"
6	283,850	51,630	Mikado

types of Switch Engines.

The total number of Switch Engines used in the daytime for switching is 53 locomotives. The total weight of these 53 engines and tenders is 5798 tons. The total number of switch engine hours is 452. Therefore the average weight of a switch engine is 109.5 tons; the average number of working hours is 8.52 per engine.

The total number of Switch engines used in the night time for switching is 53 locomotives. Total weight of these engines is 6623 tons. Total number switch engine hours is 432. Average weight of a Switch engine is 125 tons; average number of working hours is 8.3 per engine.

Ten of these engines are used for construction service. Total weight is 839 tons. Total working hours is 102. Average weight of locomotive is 83.9 tons; average number of working hours is 10.2 per engine.

FREIGHT ENGINES

Table (VI) is a list of the different types of locomotives, their weights, tractive effort, number in service, classification.

Table (VII) shows the amount of freight moving in and out of 12th street daily.

TABLE VI

No. in Service	Weight of Engine, Lbs.	Tractive Effort, Lbs.	Class
37	283,850	51,630	Mikado
3	126,000	23,299	Mogul
4	100,000	17,547	"
1	100,000	17,547	"
1	173,232	30,222	"
2	137,300	26,272	Consolidation
3	135,000	29,106	"
2	178,900	41,946	"
7	188,000	33,699	"
4	188,000	33,699	"
1	223,000	39,180	"

TABLE VII

FREIGHT TRAFFIC

ROAD TRAINS AND TRANSFERS DAILY, CHICAGO TERMINAL, RANDOLPH ST., SOUTH & WEST

NORTH OF 12TH ST.

Direction of Travel	Tonnage, Engine & Tender, 2/3 Loaded	Cars, Loaded and Empty	Total	Trains per Day	Cars per Train	Ton. per Train
Inbound	2,515	14,571	17,086	13	21	1314
Outbound	2,000	17,642	19,642	10	32	1964

SOUTH OF 12TH ST.

Direction of Travel	Tonnage, Engine & Tender, 2/3 Loaded	Cars, Loaded and Empty	Total	Trains per Day	Cars per Train	Ton. per Train
Inbound	2,544	14,120	16,664	13	25	1282
Outbound	2,049	16,075	18,123	11	30	1647

STATIONS AND STATION MILAGES

No.	Stations	Distance between Stations	Distance from Randolph
1	Randolph		
2	Van Buren	.58 miles	.58 miles
3	Central	.57	1.15
4	16th St.	.57	1.72
5	22nd St.	.58	2.30
6	26th St.	.49	2.79
7	31st St.	.62	3.41
8	Douglas	.55	3.96
9	Oakland	.38	4.34
10	43rd St.	.58	4.92
11	Kenwood	.53	5.45
12	Madison Pk	.51	5.96
13	Hyde Park	.28	6.24
14	57th St.	.50	6.74
15	60th St.	.37	7.11
16	Woodlawn Pk	.51	7.62
17	67th St.	.38	8.00
18	Brookdale	.38	8.38
19	Essex	.27	8.65
20	Grand Crossing	.34	8.99
21	Avalon Pk	.98	9.97
22	Woodruff	.49	10.46
23	Dauphin Pk	.47	10.93
24	Burnside	.81	11.74
25	103rd St.	1.00	12.74
26	Pulman	.89	13.63
27	Kensington	.55	14.18
28	Blue Island Jct	.52	14.70
29	Wildwood	.99	15.69
30	Riverdale	1.21	16.80
31	147th St.	1.51	18.61
32	Harvey	1.02	19.63
33	Hazel Crest	2.12	21.75
34	Homewood	1.37	23.12
35	Flossmoor	1.39	24.51
36	Olympian	1.67	26.18
37	Matteson	1.64	27.81

TABLE VIII

OBSERVED ACCELERATION OF STEAM OPERATED TRAINS

LOCOMOTIVES HAULING STANDARD 52 FT. CARS

Type of Locomotive	No. of Cars	Wt. of Trains Tons (Total)	Distance in Ft. Observed	Time in Seconds	Acceleration MPH/Sec.	Remarks
2-4-4	4	143	198	16	.87	Light Load
"	5	160	264	22	.75	"
"	6	185	310	28	.70	"
"	7	205	366	28	.69	"
2-4-6	4	155	210	19	1.10	"
"	5	187	261	23	.71	Heavy Load
2-6-4	7	254	367	27	.71	"
2-6-4	7	258	368	28	.65	"

TYPE OF SUBURBAN CARS

It is assumed that a 54 ton, 60 to 70 ft. long, multiple side door or end door car be used for the electric service. This car is to be equipped with 4 - 130 H.P. GE-222-6-2 600/1200 volt railway motors. A description of this motor is given on page (95). The trailer car weighs 40 tons and has the same design as the motor car. South of Kensington where the suburban trains operate on main line tracks, the side doors will not be used since the usual ground level platforms prevail. Entrance and exit will be had by means of the usual steps at the end of each car. The traffic at these stations is comparatively light, and the absence of the side door principle willhave but little effect on the duration of station stops. The arguments in favor of this type of car on the steam local runs have been noticed and its adoption seems advisable for the entire electric service. It is practically a fire

proof car, a desirable feature when electric apparatus is used. The adoption of this type permits equipment of the present side door cars with electric apparatus to convert them into standard electric trailer cars. The objection to adopting this type of car is that platforms at Cheltenham, South Chicago and Blue Island must be relocated since side door cars cannot well be loaded on a curved platform with a curvature exceeding 3 degrees.

Certain changes in construction of the side door cars are necessary to adopt it for electric operation; but these are of a miner nature.

TRAIN OPERATION

This study is based on the operation of side door cars in trains equipped with motors through-out the train, the whole controlled by one motorman by means of multiple unit control. This is the method of elevated and subway lines, and is follow-

ed by the electrified suburban lines of the New York Central, Long Island, West Jersey and Sea Shore Railway, etc; and by all interurban railways that operate cars in trains. The advantages of this method as compared with operation by electric locomotives are briefly as follows:

1. Increased rate of acceleration due to greater weight available for adhesion.
2. Decreased total train weight.
3. More efficient terminal service.
4. Increased motive power proportionate to increase of length of train.
5. Less wear on track due to distribution of weight.
6. Permits the use of one and two car-trains to be run economically during slack hours.

In order to provide interchangeability of suburban equipment it is necessary that all motor cars shall have indentical equipment as regards motor equipment and gear ratio.

STATIONS

The type of stations employed usually consists of a frame or brick depot built adjacent to the right of way with a loading platform, usually of the island type, to which admission is had by means of turnstile at the ticket seller's window. The platforms are raised to the level of the car floor (4 ft. above rail), and are provided with shelters and canopy roofs. South of Kensington, where main line tracks are used, the platforms are at rail level and hence exit and entrance from the car is by means of steps. At Randolph street, six tracks are served by three island platforms, admission to which is by means of steps leading from an overhead covered bridge spanning all the tracks. At Van Buren street a suburban station has been provided, comprising a station building 300 ft. long and 50 ft. wide, as well as platforms aggregating about 1000 ft. in length along each side of tracks 1 and 2. Two trains can be loaded at once at

Van Buren Street. The main depot of the railroad is located at 12th Street. Suburban trains do not enter this station. There is located, however, near it a complete local suburban station, but it is operated independently. The average length of station platform is 300 ft. This will permit of loading a train of eight standard suburban cars or of five side door cars.

RAILWAYS OPERATING MOTOR CAR TRAINS

Name of Rly.	Motors No.& H.P.	Tons Motor Car	Tons per Trailer	Trains made up of Motor	Trailers	Total
New York Central	2-240	54	41	5	3	8
				4	2	6
Pennsylvania RR.						
Long Island RR	2-200	40		4	2	6
Penn. Tunnel & Terminal	2-215	53		6	0	6
West Jersey & Sea Shore	2-240	47		7	0	7
do do	2-240	53		7	0	7
Southern Pacific	4-125	54	32	2	2	4
Puget Sound Electric	4-125	43		3	0	3
Great Western & M & W.L.	4-150 2-125	39	525	2	4	6

CHOICE OF SYSTEM TO BE USED

The various systems of electric traction which have been tried out more or less successfully are:

Direct current

Single phase alternating current

Three phase alternating current

Single to three phase or split phase

Single phase trolley potential with rectifiers in cab for running motors

In trying to select a system that is best suited for the Illinois Central Railroad service we will try to point out some of the advantages and disadvantages of the different systems as determined from actual operating conditions:

SINGLE PHASE ELECTRIFICATION

The principle lines equipped with single phase current are the New York, New Haven & Hartford Railroad and the Pennsylvania Railroad from Philadelphia to Paoli.

The electrification of the New York, New Haven & Hartford Railroad was decided upon in accordance with the order of New York State. It has a total of 54 miles electrified and takes in part of the direct-current inverted third rail system in the common terminal with the New York Central Railroad, when leaving New York. The outlaying part is 11,000 volt single phase, with an overhead trolley wire. The necessity of operating partly on 600 volts direct current and partly on 11,000 volts single phase greatly complicates the equipment of the locomotives which must run into the city of New York. The difficulties encountered by this road consisted in struggling against accidents due to the frequent short circuits on the trolley wire, or on the power feeders, and against the interference set up in the telegraph and telephone lines adjoining and belonging to different companies. The solution of these problems has been found, but at the price of complicated organization, delicate and costly to install and maintain.

The telephone wires have been put underground in lead covered cables; the distribution of power has been made at 22,000 volts by means of 30 compensating auto-transformers, spread over the 54 miles of the road to lessen the height of the voltage surges in the line, and to reduce the interference on the telegraph and telephone wires. The equipment includes 103 locomotives and 26 motor cars. The cost of maintenance is comparatively high and the personnel of the repair shops quite numerous. The single-phase motors are very delicate and require very careful watching of the commutator.

The Pennsylvania Railroad electrification zone is about 30 miles long. The lines from Philadelphia to Paoli are 18 miles long with 4 tracks, and from north Philadelphia to Chestnut Hill are 12 miles long with 2 tracks. The equipment includes only motor cars, not locomotives, and the service varies from suburban type to heavy traffic. Special precautions have been taken to prevent short

circuits, and the struggle against interference on the telegraph and telephone lines has been solved in the same way as on the New York, New Haven & Hartford Railroad.

From the following examples we are forced to conclude that the single-phase system is still far from the point of presenting the solution to a number of problems insufficiently solved in actual practice, notably the production of a motor capable of exerting a heavy torque for a considerable time without rotating, in order to be able to start heavy trams on the important grades. Furthermore, this system leads to complicated equipment for the protection of the neighboring telephone cirucits, which considerably augments the cost of installation. Without this consideration the cost would be distinctly less than similar costs with the three-phase and high tension direct-current system. The expenses of maintenance of the rolling stock are always higherthan in the latter two systems and the mostare less rugged and capable of less overload.

SINGLE TO THREE PHASE ELECTRIFICATION

In the single-to-three phase system the power is furnished to a single contact wire as in the single-phase form, but it is transformed in the locomotives by means of a special converter to three-phase power and the motors used with this last locomotive are three-phase induction motors. There only exists at this time one line operating with this system. It is in line from Bluefield to Vivian of the Norfolk & Western Railway. This installation may be considered to be in the test period and the maintenance expense of the rolling stock is greater than that of the other systems.

From the electrical point of view the principle inconveniences are the following: The three-phase power produced by the converter actually is not perfectly symmetrical, and the phases do not have equal currents. Furthermore, the rotors of the motors are connected to different liquid rheostats, and the loads are not always equally divided between the different motors, very often with considerable differ-

ences. A regulation of the loads by the engineer has been provided, but the latter can only make sure of a very imperfect adjustment, and the motors consequently often deteriorate rapidly. The power factor is very low, on account of the presence of the induction converter which adds its magnetizing losses to those of the motors.

In conclusion, the single-to-three-phase system, in which the principle at first glance seems very interesting, and which supplies an effectual assistance to the single-phase system by the employment of locomotives or motor cars with single-phase only for the express trains or light trains, and of locomotives single-to-three-phase for the heavy and slow trains, all these locomotives being supplied by the same trolley wire with single-phase current, is found to present in practice numerous faults which have not yet been corrected, and on account of which this system has not come up to the hopes with which it was regarded when started.

DIRECT CURRENT ELECTRIFICATION

Already the 600 volt direct current system has been utilized for a long time, in the standard method for city and suburban electric railways, either with a trolley wire for the tramways, or with a third rail for the suburban railways.

In the United States, the greater part of the interurban lines operate on 1200 volts direct current with an overhead trolley wire. A considerable number of these lines are really railroads with both passenger and freight traffic, and attain speeds of 40 to 50 miles per hour. Many of them were originally equipped with single-phase current, at voltages varying from 3000 to 6000 volts, but have been made over for direct current at 1200 to 1500 volts. The equipment for this latter voltage is now as standard as that for tramways at 600 volts.

Direct current presents the inconvenience of being a little more expensive in first cost, on account of the rotary sub-

stations required to transform the three-phase current generally produced in the central stations. Never-the-less, it must be said that to obtain economy in this regard with the single-phase installation it is necessary to generate directly the single-phase current at a low frequency by means of special electric generating groups, so that if it is wished to utilize the current produced normally by the central station it is necessary to go back to the rotary transformation, the same with the single phase as with the direct current. From this point of view, the direct current offers the advantage of being able to use the current of any station under the same conditions.

So far as the expense of operation is concerned, the complete and exact calculations compiled by the engineering services of the different companies could only show the comparison between the different systems; the writers never-the-less, estimate that the difference would not be great, and would not come into the considerationin the choice of the system.

A considerable advantage of the direct current system is that it does not seem to have any but the slightest interference with the telegraph and telephone lines, in fact insignificant. We are well able to report that one may telephone very easily on the service lines of the railroad placed all along the tracks on an aerial wire without any protection.

On account of the remarkable results obtained by the Chicago, Milwaukee & St.Paul Railroad with 3000 volts direct current, and the Butte, Anaconda & Pacific Railroad at 2400 volts direct current, the writers do not hesitate to formally conclude in favor of the adoption of this system, and we believe it to be actually the only system suitable for the electrification of heavy traction lines.

The writers choose 1200 volts as the trolley voltage because the equipment for this voltage is now as standard as that for tramways at 600 volts and that the distance to be electrified is only 28 miles long.

SELECTION OF LOCOMOTIVES

There are two general types of electric locomotives; one with all the weight on the drivers, the other with a portion of the weight carried on pony or bogie trucks. Switching and light freight traffic is handled satisfactorily by electric locomotives with driving axles only, as is also some passenger service at moderate speeds and heavy freight at slow speeds. In high speed passenger and heavier moderate speed freight service, idle trucks are more necessary.

Switching and freight services require a locomotive capable of working near the slipping point of the wheels without exceeding the overload capacity of the electric locomotive. In passenger service, high speed is demanded more frequently than great tractive power, and locomotives entirely adequate for a particular passenger run may be incapable of slipping the wheels at every start.

High powered locomotives are inherent-

ly heavier than those developing less power at the same speed. Also within reasonable limits, locomotives of the same type with equal weights, will develop power in proportion to their rated speeds. For example: - A locomotive to develop 500 H.P. at 18 miles per hour may be built to weigh 35 tons, while one to give 1000 H.P. at the same speed will weigh approximately 44 tons. However, a locomotive to produce 500 H.P. at 9 miles per hour will also weigh 44 tons.

The minimum weight of locomotive for a given service may be determined from the weights of trailing load, average car weight, speed, grades and curves, together with probable train resistance values and assumptions of acceleration rate and adhesion factors. The first step is to find the draw-bar pull required under the worst running and starting conditions.

In running, the draw-bar pull must just equal the sum of all the forces tending to stop the trailing load, which forces may

be termed resistances. Train resistance is the term applied to the friction and windage of a train in motion, and is a variable, rather uncertain in quantity. For freight trains the value of resistances will be taken from the curves drawn by Professor Edward C. Schmidt of the University of Illinois. See figure (7).

These curves were obtained from tests of 32 ordinary freight trains in regular service of such make-up as naturally resulted from the traffic conditions in the Champaign yards of the Illinois Central Railroad. The chief characteristics of these trains were as follows:

	Minimum	Maximum
Total weight of train, tons	747.00	2908.00
Average weight of cars composing the train, ton	16.12	69.92
Number of cars in the train	26.00	89.00
Train length, feet	1120.00	3480.00

The track on which these tests were made is on the Chicago division of the main line of the Illinois Central Railroad. The maximum grade against north-bound traffic was

29 ft. per mile, and against south bound traffic 31.9 feet per mile. The speed during the tests ranged from 5 to 35 miles per hour, the air temperature from 30° F. to 82° F., and the approximate wind velocity during all but one test was less than 20 miles per hour. Each train resistance was reduced to train resistance on level track by correcting for grade. The tests were made by means of a dynamometer car and only takes into consideration the train resistance of the part of the train behind the locomotive tender. The formulas corresponding to the values of train resistances given by figure (7) are:

when $W=30$ tons; $f= 5.02+0.066\ S+0.00116\ S^2$
" $=35$ " $f= 4.49+0.060\ S+0.00108\ S^2$
" $=40$ " $f= 4.15+0.041\ S+0.00134\ S^2$
" $=45$ " $f= 3.82+0.031\ S+0.00140\ S^2$
" $=50$ " $f= 3.56+0.024\ S+0.00140\ S^2$
" $=55$ " $f= 3.38+0.016\ S+0.00142\ S^2$
" $=60$ " $f= 3.19+0.016\ S+0.00132\ S^2$
" $=65$ " $f= 3.06+0.014\ S+0.00130\ S^2$
" 70 " $f= 2.92+0.021\ S+0.00111\ S^2$

Curve resistance is also variable, but an average may be taken at 0.8 pounds per ton for each degree of curvature. Grade resistance is exact, and obviously it requires

20 pounds per ton for each per cent of grade against load.

The draw-bar pull must be greater in starting than in running by an amount sufficient to accelerate the train at the desired rate. If there were no rotating parts, a force of 91.3# per ton would be sufficient to accelerate the train at a rate of one mile per hour per second. In order to allow for the effect of rotating parts, it is customary to consider 100 pounds per ton as necessary to accelerate at the rate of one mile per hour per second. For other rates the force required is in proportion to the rate of acceleration. Reasonable rates of acceleration which may be used in preliminary calculations are:-

For heavy freight	0.10 to 0.20 M.P.H.P.S.
For pick up or way freight	0.25 M.P.H.P.S.

The adhesion of driving wheels to rails is variable depending upon rail weight, weather conditions, etc. If the maximum grades are short and infrequent, adhesion

up to 25% running and 33% starting may be assumed. Where the maximum grades are long and frequent starts on grades are required, these figures are reduced to 22% running and 27% staring. In using these values of percentages for adhesion the total tractive effort for train and locomotive is used, and not the rates of draw bar pull to locomotive weight on drivers, the latter practice being commonly followed in rating steam locomotives.

A simple formula for the locomotive weight when conditions are know is:

$$W = \frac{RT}{20P-L}$$

Where W = locomotive weight on drivers (tons)
L = all resistances acting on locotives in lbs. per ton.
T = total weight of trailing loads (tons)
R = all resistances acting on trailing load in lbs. per ton.
P = assumed percentage of adhesion expressed as a whole number.
RT = draw-bar pull.

CALCULATION OF LOCOMOTIVE WEIGHTS

In calculating the weight of the electric locomotive we will assume the following values:

(a) A maximum trailing load of 2500 tons. This trailing load may consist of (1st) 40 - 60 ton cars (2nd) 50 - 50 ton cars or (3rd) 60 - 40 ton cars = T.

(b) A maximum speed of (1st) 8 miles per hour (2nd) 10 miles per hour (3rd) 12 miles per hour = S.

(c) A maximum rate of acceleration of 0.1 miles per hour = A.

(d) A maximum percentage of adhesion of 30% for starting and 25% for running = P.

(e) 0.8 pounds per ton for each degree of curvation = R_c

(f) 20 pounds per ton for each degree of grade rise = R_g

(g) 15 lbs. per ton for all resistances acting on locomotive = L.

We will then group them into the following cases and solve for the locomotive weight. (See next page).

CALCULATIONS

The maximum grade is 29 feet rise in 5280 feet or a 55% grade. The maximum curvature is a 3/4 of 1° curve. Therefore, the resistance due to the grade will be 11# per ton and that due to the curve will be 6# per ton.

The resistance of a 60 ton car at 8 miles per hour is given by Prof.Schmidt's table as 3.5 pounds per ton.

Therefore the total resistance acting on trailing load in pounds per ton is, (.6 10 11 3.5) or 25.1 pounds per ton.

The draw bar pull is 2500 x 25.1 or 62,750#.

Therefore:

$$W = \frac{62750}{20 \times 30-36.6} = 111.3 \text{ tons} \quad \text{CASE 1.}$$

$$W = \frac{(.6+10+11+3.90)2500}{20 \times 30-36.6} = 113 \text{ tons} \quad \text{CASE 2.}$$

	T.	Speed	A.	P.	R_c	R_g	L.
CASE 1.	40-60 ton cars	8 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 2.	50-50 ton cars	8 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 3.	60-40 ton cars	8 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 4.	40-60 ton cars	10 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 5.	50-50 ton cars	10 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 6.	60-40 ton cars	10 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 7.	40-60 ton cars	12 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 8.	50-50 ton cars	12 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.
CASE 9.	60-40 ton cars	12 M.P.H.	0.1	30%	0.8 lbs.	20 lbs.	15 lbs.

$$W = \frac{(.6+10+11+4.7)2500}{20x30-36.6} = 116.7 \text{ tons} \qquad \text{CASE 3.}$$

$$W = \frac{(.6+10+11+3.55)2500}{20x30-36.6} = 111.5 \text{ tons} \qquad \text{CASE 4.}$$

$$W = \frac{(.6+10+11+4.55)2500}{20x30 - 36.6} = 113.6 \text{ tons} \qquad \text{CASE 5.}$$

$$W = \frac{(.6+10+11+4.75)2500}{20x30 - 36.6} = 116.9 \text{ tons} \qquad \text{CASE 6.}$$

$$W = \frac{(.6+10+11+3.6)2500}{20x30 - 36.6} = 112 \text{ tons} \qquad \text{CASE 7.}$$

$$W = \frac{(.6+10+11+4.05)2500}{20x30 - 36.6} = 113.8 \text{ tons} \qquad \text{CASE 8.}$$

$$W = \frac{(.6+10+11+4.85)2500}{20x30 - 36.6} = 117.3 \text{ tons} \qquad \text{CASE 9.}$$

It can be seen that from these results a locomotive weighing 115 tons would be able to pull this train under normal conditions.

Under some of the worst conditions possible the percentage of adhesion would be lowered to 27% and under this case a 2500 ton train accelerated to 12 miles per hour at the rate of 0.1 mile per hour per second would have to be pulled by a locomotive weighing 130 tons.

$$\frac{(.6+10+11+4.85)2500}{20 \times 27 - 36.6} = 131.3 \text{ tons}$$

100 TON ELECTRIC LOCOMOTIVE

The electric locomotive to be used in the heavy freight service is the standard 100 ton electric locomotive built by the General Electric Company. This locomotive has a weight on drivers varying between 90 and 110 tons and is suitable for the heaviest steam railroad service. To obtain some idea of their service capacity a comparison may be made with some well known types of steam locomotives. Among road engines in steam service, 90 to 100 tons on drivers is found only on heavy freight locomotives such as the consolidation (2-8-0) and the Mikado (2-8-2) types. The Pacific (4-6-0) type, which is used principally for the heaviest passenger service has a weight of about 75 tons on drivers. Some of the Mallet types (0-6-6-0 or 2-8-8-2) have a weight as high as 200 tons on drivers, but these are practically two engines with one boiler, and their use is generally confined to pusher service. From this comparison it will be seen that an

electric locomotive of 90 to 100 tons is a unit comparable with the heaviest types of steam locomotives.

ELECTRIC EQUIPMENT

The motors are of the GE-209 commutating-pole type, wound for 600 and insulated for 1200 volts. They have a rating of approximately 300 H.P. each. At its one hour rating this motor will develop a torque of 400 lbs. at a one foot radius. The gearing between the motor and driving axle has a 4.37 reduction and the driving wheels are 48 inches in diameter. With this reduction each motor will develop a tractive effort of 8750 lbs. at the rail head, which gives a total tractive effort for the four motors of 35,000 lbs. This tractive effort will be developed at a speed of 12 miles per hour. The four motors have an overload capacity sufficient to slip the driving wheels and can develop under maximum conditions a momentary tractive effort of 50,000 lbs. to 60,000 lbs. The maximum safe speed of the locomotive running light is 35 to 40 miles

per hour.

The gears are shrunk on to an extension of the driving wheel hub and there are two gears and two pinions per motor, one at each end of the armature shaft. This form of construction is adopted on account of the unusually heavy torque and the excessive overloads to which the motors are liable to be subjected to in heavy railway service.

The control equipment is the Sprague-General Electric Type M, multiple unit, operating the four motors in series and series parallel. Two 600-volt motors are permanently concected in series. The controller provides ten steps in series and nine in series parallel. The transition between series and series parallel, is affected without opening the motor circuit and there is no appreciable reduction in tractive effort during the change. The transfer of circuits at this point is made by a special change-over switch, which is operated electro-pneumatically.

A CP-26 air compressor set furnishes the air for operating the brakes, whistles and sanders. This outfit consists of a two stage, four cylinder compressor, geared to a 600 volt series wound direct current motor. It has two low and two high pressure cylinders, arranged to divide the work of compression into four equally distributed impulses per revolution and has a capacity of 100 cu.ft. piston displacement per minute when pumping against a tank pressure of 135 lbs. Circulating pipes are provided for cooling the air between stages and between the pump and tanks so that the temperature may be maintained at a moderate value. The compressor is controlled by a governor consisting of a pneumatically-operated piston arranged to close or open the motor circuit at any predetermined pressure limits.

The motor is designed for forced ventilation. Air is delivered into the back end of motor frame, passes between the field coils and around the armature and finally escapes through suitable discharge openings

over the commutator. The blower used for this purpose has a capacity of 2000 cu. ft. per minute and it is driven by a direct current series motor. The air is delivered to a compression chamber formed between the center sills of the locomotive platform from which ventilating ducts are tapped off to the motors at appropriate points.

The 1200 volt contactors are operated from the 600 volt control circuit, and are specially constructed to separate the 1200 volt parts from the coils and interlocks which carry the 600 volt current. The necessary insulation is obtained by large clearances and by the use of porcelain and mica. The armature is connected to the contact lever by a wooden rod. The contacts, magnetic blowout and arc shuts are also especially designed to rupture the 1200 volt arc.

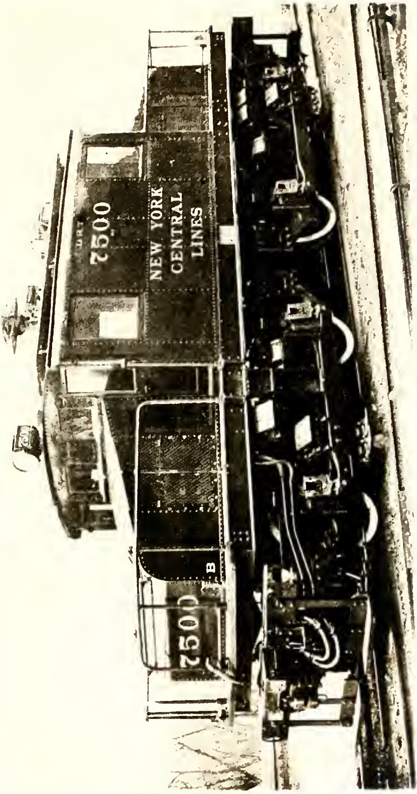
For operating the control equipment and air compressor and for lighting the locomotive and cars, 600 volt current is supplied from the 1200/600 volt dynamotor installed on each locomotive.

GENERAL DIMENSIONS AND SPECIFICATIONS

Length inside of knuckles	39 ft. 6 in.
Length over cab	33 ft. 6 in.
Height over cab	12 ft. 4 in.
Width over all	10 ft. 1 in.
Total wheel base	27 ft. 6 in.
Rigid wheel base	9 ft. 6 in.
Weight electrical equipment	60,000 lbs.
Weight mechanical "	140,000 lbs.
Weight total	200,000 lbs.
Body construction	All steel
Underframe	10" channels
Body bolster	3 plates 12" by 1"
Trucks	Locomotive type
Wheels	48" diam.,steel tired
Truck bolsters	steel castings
Springs	42" half elliptic, 5" by 7/16" plates.
Journals	7 1/2" by 14"
Motors	Four GE-209
Gears	83 teeth
Pinions	19 teeth
Control	Type M multiple unit
No. of steps	10 series,9 series parallel
Max. tractive effort (with sand)	60,000 lbs.
Corresponding tractive coefficient	30%
Tractive effort at one hour rating	36,000 lbs.
Corresponding tractive coefficient	15%
Tractive effort continuous	18,800 lbs.
Corresponding tractive coefficient	9.4%
Air brakes	Combined straight and automatic
Air compressor	Gen.Electric CP-26
Brake Shoes	Cast iron, steel plate back

Couplers	M.C.B.
Sanders	Double end, pneumatic
Trolley	Short pantograph U.S.119A

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
BY
R. W. BROWN R. S. ELLG D. J. MALPEDE
Figure No. A



STANDARD 100-TON GENERAL ELECTRIC LOCOMOTIVE.

Electrification of the
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at Chicago, Ill.
BY
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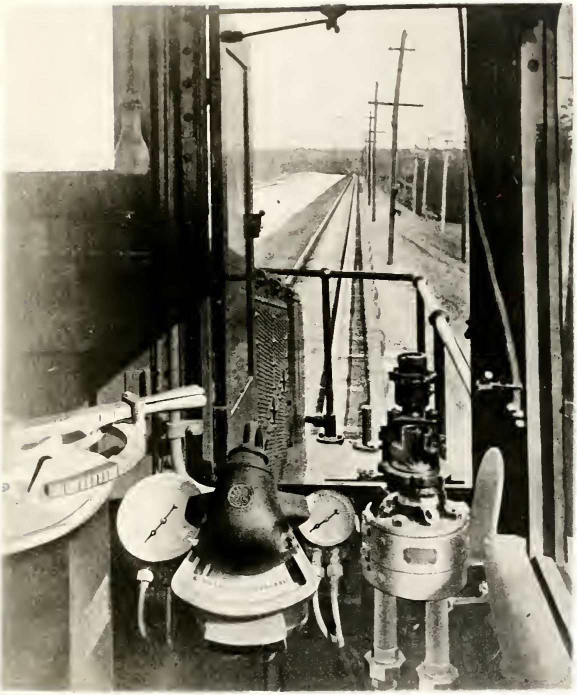
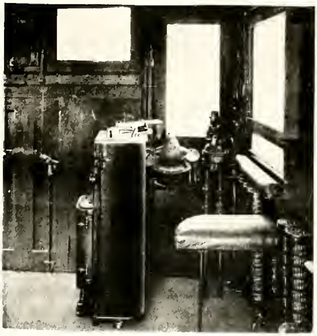
Figure No. B

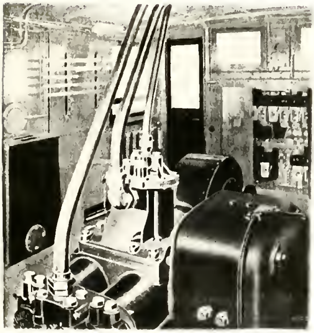


VIEW FROM ENGINEERS SEAT 100-TON ELECTRIC LOCOMOTIVE.

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—BY—
R. W. BROWN R. S. ELLG D. J. MALPEDE
Figure No. C

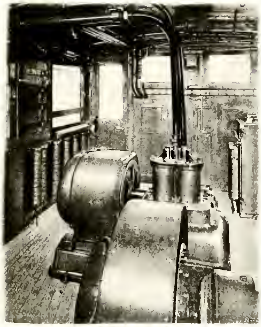


CONTROL APPARATUS

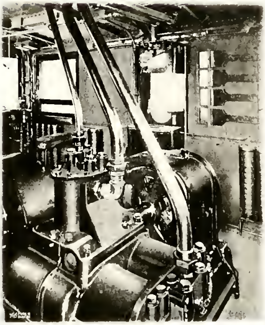


AIR COMPRESSER AND CONTACTORS.

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—BY—
R. W. BROWN R. S. ELLG D. J. MALPEDE
Figure No. D



MOTOR-DRIVEN BLOWER



MOTOR-DRIVEN COMPRESSOR.

BANK OF 1200 VOLT CONTACTORS IN
G.E. 100 TON LOCOMOTIVE.

60 TON SWITCHING LOCOMOTIVE

The electric locomotive to be used in the switching service is the standard 60 ton electric locomotive built by the Westinghouse Electric Company. The mechanical parts of these locomotives are designed and manufactured by the Baldwin Locomotive Works. The electrical equipment is made and installed by the Westinghouse Electric & Manufacturing Company. This locomotive is of the steeple cab type and designed for double-end operation. It is of the double swivel type with a cab of ample dimensions in the center, and with hoods at each end.

Baldwin-Westinghouse electric locomotives are rated for a maximum tractive effort (on clean dry rails) of 25 per cent of the weight of the locomotive. With dry sanded rails a locomotive may exert a tractive effort equal to 30 to 35 per cent of its weight on the drivers.

ELECTRICAL EQUIPMENT

All of the main-circuit control apparatus and the resistors are mounted in the center of the locomotive and surrounded with suitable expanded metal screens forming a cage as a protection against accidental contact. In the right-hand corner of the cab are mounted the master controller, engineer's brake and sander valves. The reversers and the control resistors are placed next to the floor, the switches directly over them, and the resistors directly over the switch groups under the roof. See figures (F).

When forced ventilation is used on these locomotives, a centrifugal motor-driven blower is installed in one or each of the hoods. These blowers force air through a conduit built in the locomotive frame between the channels forming the center sills whence it passes to the main motors through flexible canvas connections. The use of the blower motor increases the continuous current capa-

city of the locomotive from 30 to 100 per cent.

MOTORS

This locomotive is equipped with four Westinghouse No. 308-D-3 box frame, commutating-pole motor and type H.L. unit switch control. The motors are mounted in the usual manner using nose suspension. The motor has the following ratings:

ONE HOUR RATING - 225 H.P. at 600 volts and 315 amperes with natural ventilation.

CONTINUOUS RATING - 140 Amperes at 300 volts, with perforated covers.
200 Amperes at 500 volts, with forced ventilation.

NORMAL SPEED - 590 R.P.M. at 600 volts with natural ventilation.
580 R.P.M. at 600 volts with forced ventilation.

CONTROL EQUIPMENT

The type HL unit switch control is recommended for use with the No. 308-D-3 motor. This type of control has the following advantages:

1. There are no heavy current-carrying parts on the platforms.

2. Minimum platform space required.

3. The various details such as switches, blow-out coils, and cylinders are designed as units so that any unit may be removed for inspection and repair by taking out two bolts and without further dismantling the apparatus.

4. The main contacts are closed penumatically with great and uniform pressure.

5. Powerful springs open the contacts assuring positive action.

6. The magnetic blow-out is exceptionally effective.

7. Will operate satisfactorily on practically any voltage.

GENERAL DIMENSIONS AND SPECIFICATIONS

MECHANICAL DATA.

Type of truck	0-4-0 swivel
Rigid wheel base	7'4"
Total wheel base	25'0"
Length between coupler knuckles	35'0"
Total height over cab roof	11'5 1/2"
Diameter driving wheels	36 1/2"
Total weight	123,500 lbs.
Weight per driving axle	30,875 lbs.

HAULING DATA.

Continuous tractive effort	11,520 lbs.
One-hour rating at 17.6 M.P.H.	21,600 lbs.
Maximum tractive effort	30,000 lbs.

TRACK PROFILE	NUMBER OF 45-TON CARS	MAXIMUM SPEED M.P.H.
Straight level track	50	18.4
0.5% Grade	26	17.6
1.0% Grade	16	17.6
2.0% Grade	8	17.6

EQUIPMENT

Number of motors	4
Type of motors	308-D-3
Horse power per motor	225 H.P.
Total horse power	900
Control	Type HL
Dia. wheels	36 1/2"
Brakes	Type EL Westinghouse Air
Trucks	Double swivel type
Couplers	M.C.B.
Sanders	Leach pneumatic type
Whistle	Clarion type
Headlights	Dressel incandescent
Current collector	Nuttall pantograph

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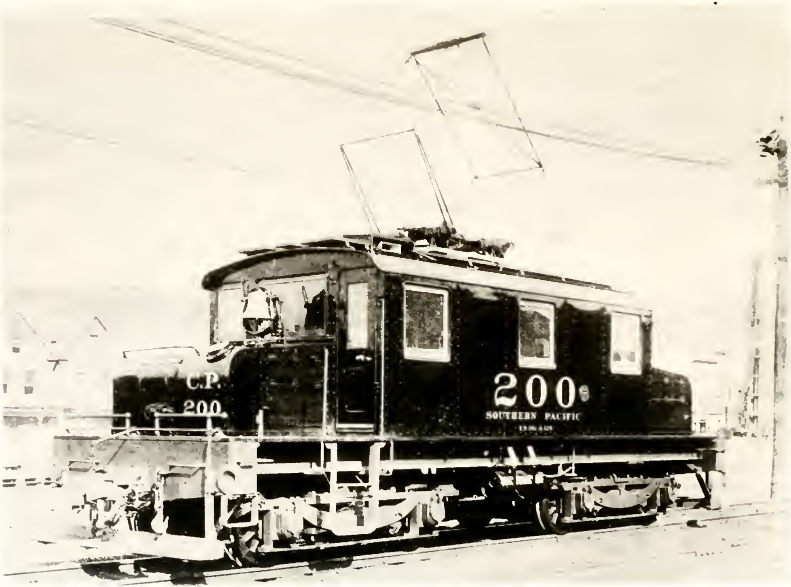
Figure No. E



60-TON BALDWIN-WESTINGHOUSE 600/1200 VOLT SWITCHER LOCOMOTIVE
4-WESTINGHOUSE 308-D-3 RAILWAY MOTORS TYPE HL CONTROL

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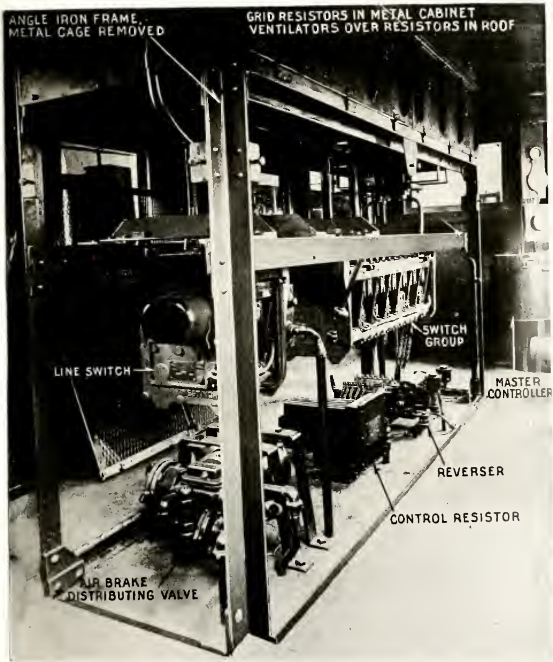
Figure No. F



Centralization of Equipment—Cab Interior of a Baldwin-Westinghouse Locomotive
Showing Control Equipment after Metal Screen has been removed

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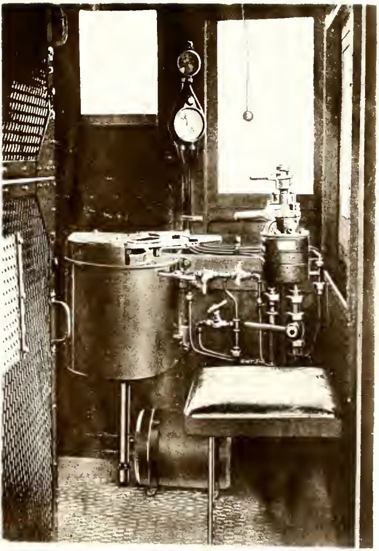
Figure No. 6



CONTROL APPARATUS 60-TON SWITCHER LOCOMOTIVE.

MAXIMUM SPEEDS

The maximum speeds of the present express trains on the runs from Van Buren St. to Hyde Park is about 40 miles per hour. It is necessary to increase this speed to 50 miles per hour in order to produce the desired improvement in the schedule time for this particular run. It is apparent from this that no equipment can be considered unless it will propel a train at about 50 miles per hour, on straight level track. This maximum speed is about typical of American suburban trains when electrically operated. The six car trains of the New YorkCentral R.R. operating in the New York electric zone, are geared for about this maximum speed. The Long Island Ry. electric suburban trains will operate at 45 miles per hour. The West Jersey & Sea Shore Railroad trains however, operate at 60 miles per hour.

The maximum speed that will be obtained in the express run with an average of

one trailer car per motor car will be about 55 miles per hour. For the local it will be about 45 miles per hour. The motor car being equipped with 4 - 130 H.P. GE-222-6-2 motors.

COASTING - BRAKING - DURING OF STOPS

The method of determining power and speeds used in this study is on the basis of a small amount of coasting from the time of shutting off power to the time of applying brakes. The amount is but 10 to 20 sedonds depending on the length of the run. In addition 3% of the time thus determined is added to obtain the time table schedule time.

The rate of retardation during braking is assumed at 1.5 miles per hour, per second. This corresponds to 7.1% of train weight adhesion.

The length of stop is assumed to be 15 seconds at all stations. Extended observations have shown these to be conservative values for trains of side door cars. In addition to regular station stops there is

supposed a 12 second stop at the combination switch at 12th Street for all express trains, both north and south bound.

TRAIN RESISTANCE

Information regarding train resistances at constant speed is necessary to properly determine the ultimate maximum speed as well as the instantaneous rates of acceleration at any lower speed. Very satisfactory data is available at the present time regarding train friction of electrically operated trains. In this study the value of train resistances are taken from sets of curves deduced from data of A.H.Armstrong. The freight train resistances are taken from curves deduced from data obtained from the test of Illinois Central freight trains at Champaigne, Illinois.

MOTORED CARS

CASE 1

In this case we are not taking into consideration the grades or curves. Our reason for doing this is because there are no grades worth considering until one gets out toward the end of the main line electrification. The two branch lines, South Chicago and Blue Island, contain no grades so our motors selected according to this case will be correct. The grade at the end of the main line is a .55 of a 1% grade and is several miles long. The vaulue of train resistance due to this grade is 11 pounds per ton. This resistance will have a noticeable effect on the rate of acceleration of the train. In order to keep the current taken by the motors the same as in the other runs, the rate of acceleration will probably drop to .65 miles per hour per second and the velocity on running to about 35 miles per hour.

There are no severe curves around which the fast trains will pass, the greatest

being 3/4 of 1° curve. The value of train resistance due to this curve is .6 pounds per ton which is so small that it can be neglected.

SELECTION OF A MOTOR FOR A LEVEL ROAD BED

The maximum length of train to be used is one made up of these motored cars and three trailer cars. The motored cars are to weigh 54 tons and the trailers 40 tons. Dead weight of train = 3 x 54 + 3 x 40 = 282 tons. Allowing 6-1/2 tons per car for passengers the total weight of train is equal to 321 tons. Assuming a maximum speed of 45 miles per hour the value of train resistance for a 54-ton car is approximately 7 pounds per ton, and for the trailer car 7.5 lbs. per ton. These values of train resistances are obtained from Figure (5). The total train resistances on running = 3(54 + 6.5)7 3(40 + 6.5)7.5 = 2316 pounds or 193 pounds per motor.

The initial constant acceleration will be assumed as 1.00 m.p.h.p.s. A force

for acceleration will then be $3(54+6.5)(7+100)+3(40+6.5)(7.5+100) = 34,415$ pounds or 2868 pounds per motor. In order to get the gross tractive effort, the value of train resistance must be approximated? This may be done sufficiently accurate by selecting the value corresponding to the average speed which must be assumed for the constant acceleration period. Taking this average speed as 13 m.p.h. (f) the train resistance is equal to 4.5 pounds per ton. $p = 100 + 4.5 = 104.5$ pounds per ton = force necessary to accelerate one ton at the rate of 1.00 m.p.h.p.s. The gross tractive effort per motor is therefore T.E. $= \frac{321}{12} \times 104.5 = 2795$ pounds per motor. Referring to the characteristic curves of this motor (Fig. 28) the current and speed for this tractive effort are

$I = 275$ amps.

$V = 25$ miles per hour

The average speed from the start is therefore

12.5 miles per hour which proves that the assumption of 13 miles per hour used in obtaining the value of train resistance (5) was sufficiently accurate.

The time required for the period of constant acceleration is $t = \frac{25}{1.00} = 25$ secs. This determines one point A on the distance-speed-time curve Fig (33). In order to determine the first point B on the curved portion of the speed-time curve acceleration diagram, an increment of speed must be assumed.

Let $dV = 4$ m.p.h. $V \; dV = 29$ m.p.h. The gross tractive effort on the characteristic curve Fig.(28) corresponding to 29 m.p.h. is

$$T.E. = 1600 \text{ lbs.}$$

The average speed for this increment being $\frac{25 + 29}{2} = 27$ m.p.h., the new value of train resistance (f) will be found from the resistance curves to be

$$f = 5.2 \text{ lbs. per ton Fig.}$$

The new value of net tractive effort is, there-

fore

$$p' = \frac{1600}{23.5} - 5.2 = 62.88 \text{ lbs. per ton}$$

The corresponding value of acceleration is

$$A' = \frac{62.8}{100} \times 1.00 = .628 \text{ m.p.h.p.s.}$$

$$dt = \frac{4}{.628} = 6.36 \text{ seconds}$$

The coordinates of the point "B" are, therefore

$$V + dv = 29 \qquad t + dt = 31.3 \text{ secs.}$$

MOTORED CARS

The minimum length of train to be used is one made of three cars: two motor cars and one trailer.

Dead weight of train = 2 x 54 40 = 148 tons. Allowing 6-1/2 tons per car for passengers the total weight of train is equal to 2(54 + 6-1/2) + (40 + 6-1/2) = 167.5 tons. Proceeding the same way as we did before, we get the following results.

Train resistance on running = 1195 lbs. per train or 143 lbs. per motor.

Force for acceleration = 17,945 lbs. per train or 2243 lbs. per motor.

Gross tractive effort per motor,

$$\text{T.E.} = \frac{167.5}{8} \times 104.5 = 2188 \text{ lbs. per motor.}$$

CALCULATED DATA SPEED-TIME CURVES

Point	dV	T.E.	f	p'	A'	dt	t + dt	V+dV
B	4	1600	5.2	62.8	.628	6.36	31.3	29
C	10	920	5.5	33.7	.337	29.7	54.7	35
E	20	400	5.75	11.25	.112	178	203	45
D	15	650	5.65	22	.22	68.5	93.5	40

MOTORED CARS CASE 2

In this case we are taking into consideration the Grades. The grade for which we are selecting a motor is the .55 of 1% grade which is located at the end of the main line. This grade is very long and contains four stops for the suburban traffic.

MOTORED CARS - CASE 2

54 tons Motored Cars, 40 ton Trailers. Maximum train , 3 motor cars and 3 trailer cars. Dead weight of train = 3x54 3x40 = 282 tons. 6.5 tons per car for passengers.

From the curve Figure 24, Standard Railway Handbook, the resistance of a 54-ton car at 42 miles per hour = 7 lbs. per ton; the resistance of a 40-ton car at 42 miles per hour = 7.5 lbs. per ton. The resistance due to .55% grade = 11 lbs. per ton.

Total resistance = 3(54 + 6.5) +(7 + 11) + 3(40 + 6.5)(7.5 + 11) = 3267 + 2580 = 5847 lbs. per train on running or 487 lbs. per motor (12 motors.)

The initial constant acceleration will be assumed as 1.25 miles per hour per second. A force of 100 lbs. per ton will be considered as the necessary tractive effort to overcome the inertia of both translation and rotation in accelerating the car at a rate of 1 m.p.h.p.s.

The force for acceleration will

then be 3(54 + 6.5)(11 + 125 + 7) + 3(40 + 6.5)(11 + 125 + 7.5) = 45972 lbs. or 3831 lbs. per motor.

In order to get the gross tractive effort the value of train resistance must be approximated. This may be done sufficiently accurate by selecting the value corresponding to the average speed which must be assumed for the constant acceleration period.

Taking this average speed at 11 m.p.h. (f) the train resistance = 4 lbs. per ton. Grade resistance = 11 lbs.

$$P = 125 + 11 + 4 = 140 \text{ lbs. per ton}$$

The gross tractive effort per motor is therefore

$$T.E. = \frac{282}{12} \times 140 = 3290 \text{ lbs.}$$

Referring to the characteristic curves of this motor Fig. (28) the current and speed for this tractive effort are

$$I = 248 \text{ Amps.}$$

$$V = 21.5 \text{ m.p.h.}$$

The average speed from the start

is therefore 10.75 m.p.h. which proves that the assumption of 11 m.p.h. used in obtaining the value of train resistance (f) was sufficiently accurate. The time required for the period of constant acceleration is

$$t = \frac{21.5}{1.25} = 17.2 \text{ seconds}$$

This determines one point A on the distance-time curve.

MOTOR CAR TRAINS

In order to determine the first point B on the curved portion of acceleration diagram, an increment of speed must be assumed.

Let dv = 4 m.p.h., or v dv = 25.5 m.p.h. The gross tractive effort on the characteristic curve corresponding to 25.5 m.p.h. is

T.E. = 1700 lbs.

The average speed for the increment being $\frac{21.5+25.5}{2} = 23.5$ the new value of train resistance (f') will be found from the resistance curves to be. (Fig.5)

f' = 5 lbs. per ton

The new value of net tractive effort is, therefore,

$$p' = \frac{1700}{23.5} - 5 = 72.3-5 = 67.3 \text{ lbs.per ton}$$

The corresponding value of acceleration is

$$A' = \frac{67.3}{125} \times 1.25 = .673 \text{ m.p.h.p.s.}$$

$$dt = \frac{4}{.673} = 5.94 \text{ seconds.}$$

The co-ordinates of the point B are therefore $(V+dv) = 25.5$ m.p.h. and $(t+dt) = 23.14$ secs.

Calculated Data, Speed - Time Curves

Point	dv	T.E.	f'	p'	A'	dt	t dt
B	4	1700	5	67.3	.674	5.94	23.14
C	15	700	5.5	24.3	.243	61.7	78.9
D	36.5	450	5.75	13.42	.134	152.7	169.9

For the three car motor train we get the following results. Wt. of train = 2 x 54 + 40 = 148 tons = dead weight. Allowing 6.5 tons per car for passengers. Total weight of train loaded = 2(54 + 6.5) (40 + 6.5) = 167.5 tons. From Fig.(4) the train resistance of a 54 ton car at 42 m.p.h. = 8.5 lbs. per ton, and the resistance of a 40 ton car at 42 m.p.h. = 9.5 lbs. per ton. Grade resistance = 11 lbs. per ton. Total train resistance at 42 miles per hour = 2(54 + 6.5)(85 + 11) + (40 + 6.5)(9.5 + 11) = 3313 lbs. or 414 lbs. per motor = necessary T.E. that each motor must produce at 42 miles per hour. The necessary tractive effort on starting = 2(54 + 6.5)(8.5 + 11 + 125) (40 + 6.5)(9.5 + 11 + 125) = 24,250 lbs. or 3,032 lbs. per motor. Assuming an average speed of 11 miles per hour during the constant acceleration the value of train resis-

tance = 4 lbs. per ton.

$$p = 125 + 11 + 4 = 140 \text{ lbs. per ton}$$

The gross tractive effort per motor is, therefore,

$$T.E. = \frac{167.5}{8} \times 140 = 2930 \text{ lbs.}$$

Referring to the characteristic curves of this motor Fig. (28) the current and speed for this tractive effort are

$$I = 250 \text{ amp.}$$

$$V = 210 \text{ m.p.h.}$$

The time required for the period of constant acceleration is

$$t = \frac{21.0}{1.25} = 17 \text{ seconds.}$$

This determines one point A' on the distance-time curve. In order to determine the first point B' let $dv = 5$, $v + dv = 26$

The gross tractive effort on the characteristic curve corresponding to 26 m.p.h. = T.E. = 1550 lbs. Average speed for this increment is 23.5 M/H and the value of the train resistance is

$$f' = 6 \text{ lbs. per ton}$$

The new value of the net tractive effort is therefore

$$p' = \frac{1550}{20.9} - 6 = 68 \text{ lbs. per ton}$$

The corresponding value of acceleration is

$$A' = \frac{68}{1.25} \times 1.25 = .68 \text{ m.p.h.p.s.}$$

$$dt = \frac{5}{.68} = 7.5 \text{ seconds.}$$

The co-ordinates of the point B' are, therefore $(V + dv) = 26$ m.p.h. and $(t + dt)$ $= 24.5$ seconds. In the same way the points C', D' and E' were found.

COASTING TIME

In order to put in the coasting line at the proper slope the area under the three curves must represent 1563 feet, 4730 feet and 9852 feet. The slope is determined by the forces tending to slow the car down after the power is shut off; that is, train resistance, gear losses, and motor friction and windage. Theoretically, the coasting line would be curved, as the retarding forces decrease as the car slows down; practically no great error is involved, and considerable work is saved by assuming the retarding force constant and equal to the train resistance at the speed at which power is cut off. The neglect of the motor friction and windage is at least partly offset by the neglect of the decreased train resistance as the speed comes down.

Assuming that the power is shut off at 26.5, 38 and 45 miles per hour for the six car train, and 27, 38 and 48 miles per hour

for the three car train, the value of train resistance vary from 5.5 pounds per ton to 11 pounds per ton, which corresponds to a retardation rate of from .055 to .11 miles per hour. Putting in the coasting lines at these slopes the areas are found to correspond to the length of the runs.

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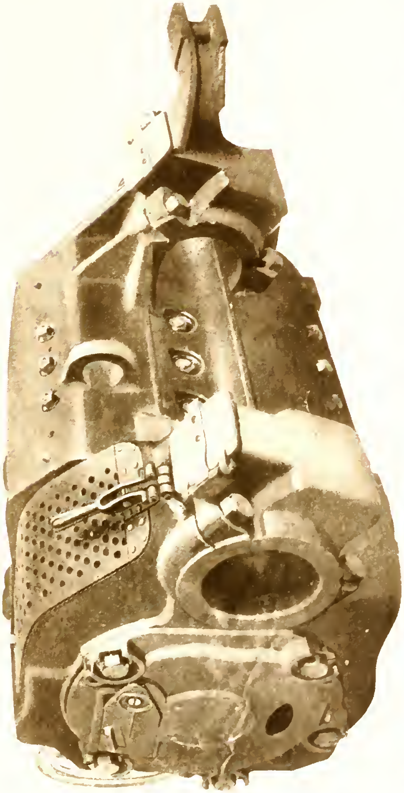
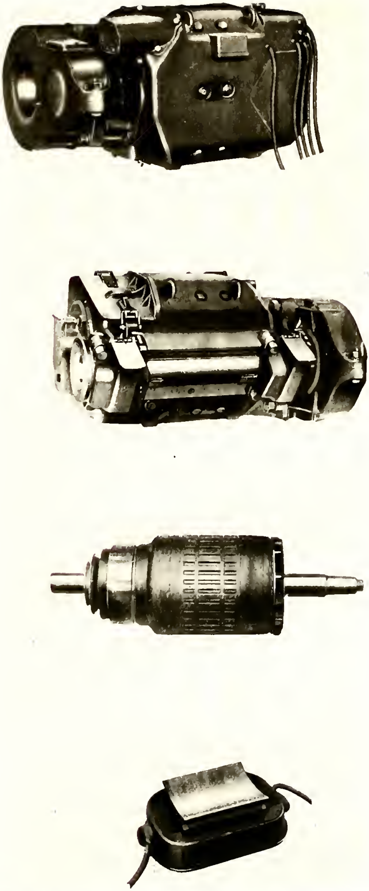
Figure No. H

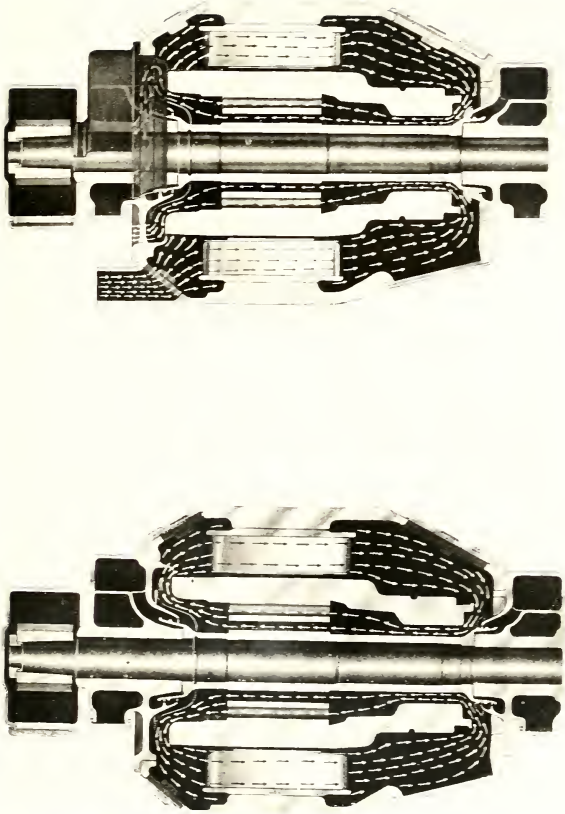


WESTINGHOUSE BOX FRAME COMMUTATING-POLE RAILWAY MOTOR
308-0-3 FOR 600/1200 VOLT OPERATION 225 H.P.

Figure No. I



GE-222-G 600/1200 VOLT RAILWAY
MOTOR 130 H.P.



VENTILATION OF G.E-222 RAILWAY MOTOR

CURRENT TIME CURVE

In order that the power which will be taken by a car on a given run may be predetermined the current and voltage time curves must be plotted. Since the voltage is usually assumed constant at some average value which may reasonably be expected to obtain over the entire line its graphical representation is merely a straight horizontal line.

With the current, however, it will be remembered that the control equipment is expected to maintain practically constant current values in each motor until the net tractive effort falls below that necessary for the initial assumed acceleration. This point, which is represented by (A) on the speed-time curve (Figure 30) has its time co-ordinate definitely fixed. The current per motor (I), as found from the characteristic for this particular speed might be plotted as constant from the start to a point (t = oa'). Since, however, the series

parallel control is ordinarily used, and the current consumption for two motors is the important consideration, it is usually assumed that during the first half of the time (oa')(Figure 30), the motors are in series and during the latter half period in parallel. The current consumption for two motors is, therefore, double the value in the latter or parallel half that it is in the first or series half of the constant acceleration portion of the run.

The gross tractive effort during the constant acceleration period (oa')(Figure 30) was found to be 3831 lbs. which required a current value per motor of 295 amperes for the six car train. The gross tractive effort during the constant acceleration period was found to be 3,032 lbs. which required a current value per motor of 252 amperes for the three car train. During the first half of this same period the current per pair of motors is 590 and 504

amperes. In the second or parallel half of the period, however, the corresponding values of current are 1180 and 1008 amperes. In determining the other points on the current curve such as the current after 100 seconds have elapsed, it is found from the speed time curve that the speed is 38.5 miles per hour for the six car train and 41 miles per hour for the three car train. Referring to the characteristic curves of this motor the current corresponding to these speeds are 87.5 amperes and 80 amperes per motor or 350 amperes and 320 amperes per car since all four motors are now operating in parallel.

PASSENGER LOCOMOTIVE WEIGHTS

Corresponding values for passenger trains may be obtained from figure (3) which is based on the formula -

$$R = 4 \frac{V}{10} + \frac{1000\ V^2}{3600\ T}$$

Where R = train resistance in pounds per ton.

V = speed in miles per hour.

T = weight of train in tons.

Assuming a maximum speed of 60 miles per hour.

$$R = 4 + \frac{60}{10} + \frac{1040x3600}{3600x1040} = 11\#\text{ per ton.}$$

This formula is calculated on the basis that the trailing load is 1000 tons and allowing 40,000 pounds for each of the two four wheel idle or bogie trucks.

Assuming an acceleration of .5 mi. per hr. per sec.

Using the same formula as in the calculation of the freight locomotive weight -

$$W = \frac{RT}{20\ P-L}$$

T = trailing load in tons = 1040

R = all resistances acting on trailing load =

R_c = .6# R_g = 11# R_a = 50# R_w = 11#

Assuming 30% coefficient of friction -

RT = (.6+11+10+50) 1040= 74,464#

Locomotive resistance = 15# per ton

$$W = \frac{RT}{20\ P-L} = \frac{74,464}{20x30 - 86} = 145 \text{ tons}$$

THROUGH PASSENGER TRAIN CALCULATIONS

THROUGH PASSENGER SERVICE

The various through passenger trains vary in weight from about 500 tons to 1100 tons. The average weight of train including locomotive will be assumed as 900 tons, which is a conservative figure. Assuming a maximum speed of 45 - 50 miles per hour, the train resistance for 75 ton cars is 6# per ton (see Fig. 3). The locomotive weight being 130 tons, the trailing load is 900 - 130 = 770 tons. Loco. res. = 15# per ton.

Train res. = (770 x 6) + (130 x 15) =

4620 + 1950 = 6570#.

As the locomotive will contain 8 motors (see description on page) the tractive effort required of each motor is:

$$\frac{6570\#}{8} = 822\# \text{ per motor}$$

The performance curves of the Westinghouse 308- D railway motor of 225 - 250 H.P. and gear ratio $\frac{50}{23}$ indicate that this motor may be used.

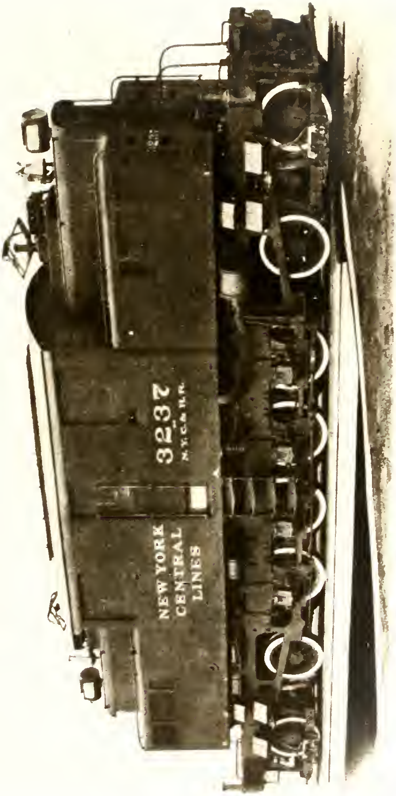
Assuming .5 mile per hour per second for

Electrification of the Illinois Central Railroad Terminal at Chicago, Ill.

—BY—

R. W. BROWN R. S. ELLG D. J. MALPEDE

Figure No. K



120 TON PASSENGER LOCOMOTIVE 8-225 H.P. MOTORS.

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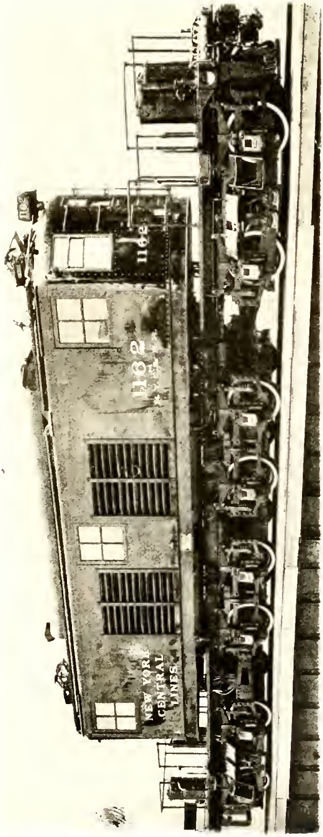
R. W. BROWN R. S. ELLG D. J. MALPEDE

Figure No. 2



130 TON PASSENGER LOCOMOTIVE 8-225 H.P. MOTORS.

acceleration, the force required is:

90 x 100 x .5 = 45,000# tractive effort.

$\frac{45000}{8}$ = 5625# per motor for acceleration .

This tractive effort corresponds to a speed of 25 miles per hour and a current of 555 amperes.

Constant acceleration of .5 miles per hour per hour per second can then be maintained up to 25 miles per hour.

The points on the speed time curve were calculated as before and plotted.

ENERGY REQUIREMENTS

A knowledge of the amount of electric energy which will be required to operate the Illinois Central Terminal is essential in the development of the plans of the transmission system and substations. The determination of the amount of energy required has been based upon a knowledge of the total volume of traffic to be handled within the proposed limits of electrification.

The amount of energy in kilowatt-hours which will be required at the cars or locomotives or "at the pantograph" has been determined by multiplying the number of ton-miles in each class of service by the unit representing the watt-hours per ton-mile in that service. These units are determined initially by the well-known time-speed curve method in the case of the suburban and through passenger service. Curves of the characteristics of motors of this type and types selected for several classes of locomotives and multiple-

unit cars were obtained from the manufacturers. See figures(8-29). These combined with data regarding the length of run, the speed, the weight of trains and other factors which were developed as a result of the tests described in TABLE (6), and with train resistance formulas gathered from the most reliable sources, formed the basis of the calculations from which the time-speed curves were made. The geographic distribution of the energy at the pantograph was determined by applying the energy units to the ton-miles of electric traffic for each class of service over each route element within the proposed limits of electric operation.

To the theoretical units which were obtained from the time-speed diagrams, certain percentages were added to cover lighting and heating in the case of multiple-unit service, severe weather conditions, traffic delays, air compressor motor requirements and indetermine operating losses which experience has shown to exist.

The energy demand per 1000 ton miles

for railway freight service varies widely because of the switching service and the irregularity of the length of freight hauled. An average has been made of a number of tests on heavy railway freight service, particularly tests on the recently electrified sections of the Chicago, Milwaukee & St.Paul Railroad. These with due allowances for losses in distribution and the transmission system, give an average of approximately 33 watt-hours at the substation per ton mile moved over the railroad. For contingencies we might increase this item approximately 20 per cent and we have assumed in the calculations 40 watt-hours per ton mile as an amply conservative basis for estimating the electric energy.

After taking into account all these factors, the following energy units were adopted:

Yard, road freight, freight transfer.	40 Watt-hours.
Through passenger	35 Watt-hours.
Suburban passenger	80 Watt-hours.

TABLE 9

TOTAL NUMBER OF TON MILES TO BE HANDLED UNDER ELECTRIC OPERATION FOR THE AVERAGE DAY.

YARD FREIGHT	522,125
ROAD FREIGHT	773,644
TRANSFER FREIGHT	460,592
TRANSFER PASSENGER	414
MAKE UP and PUT AWAY	15,714
MULTIPLE-UNIT	1,310,000
THROUGH PASSENGER	316,400

TABLE 10

TOTAL NUMBER OF KW PER DAY USED BY THE ILLINOIS CENTRAL RAILROAD

SERVICE	KW-HR PER DAY	AV.KW PER HR.
YARD FREIGHT	20,885	871
ROAD FREIGHT	30,945	1290
TRANSFER FREIGHT	18,423	768
TRANSFER PASSENGER	17	.7
MAKE UP and PUT AWAY	629	26.2
MULTIPLE UNIT	108,200	4366
THROUGH PASSENGER	12,649	527

SWITCHING STATIONS

With the 1200 volt system it is necessary to provide switching stations at various points throughout the terminals for the sectionalization of the overhead conductors of the contact system. Such switching stations will consist of suitable apparatus to allow conductors to be isolated in the event of disorder due to overload, short circuits or other causes.

Switching stations for main track contact condutors in the terminal are to be provided as follows:

1. At intervals of from two to three miles, usually at interlocking plants or passenger stations where there are crossovers.
2. At all important junction points.
3. At all track crossings at grade.

A substation has been considered as serving the purpose of a switching station and as taking the place of one that would otherwise be required. Carbon break circuit

breakers mounted on slate panels are to be used as the switches. This type of switch requires protection from the weather, and for this reason a small and inexpensive building is to be provided at each location selected for a switching station.

SUBSTATIONS

The substations for the 1200 volt direct current system are designed to receive three-phase, 25 cycle alternating current at 20,000 volts and to convert it into 1200 volt direct current for the contact system. The general considerations governing the locations selected for substations are as follows:

1. Substations are to be placed where distribution of power may be made in several directions.
2. Substations are to be located near large yard loads were possible.
3. Substations are to be located where they may be reached by two separate transmission routes.

The 1200 volt substations are to be so located as to secure economical distribution

of current to the load and low potential drop in the return circuit. With the locations selected, the drop in voltage in the positive distributing system under maximum starting conditions will not exceed 200 volts. This requires that the distance between substations shall not be more than from 4 to 6 miles.

The 1200 volt direct current system provides for 6 substations varying in capacity from 3000 to 7500 kilowatts. Each substation is to consist of a suitable brick building located on railroad property and equipped with a hand-operated crane for handling the heavy apparatus. The apparatus will consist of lightning arresters and oil switches on the incoming three-phase circuits, transformers, switch-boards with the necessary instruments, and rotary converters. The substations are to be equipped with General Electric standard 1200 volt - 1500 KW - rotary converters and 1200 volt standard switchboards. The transformers are to be of the air blast type.

The substation equipment to be provided, including rotary converters and transformers, may be operated for five minutes at a load 200 per cent in excess of the rated capacity. A spare unit is to be provided at each substation, thus permitting the maximum load to be carried with one unit out of service.

The location of the substations and the routes of their connecting transmission lines are shown by figure(43). The number, capacity, etc. of the substations to be provided are set forth in table (XI).

TABLE XI

SUBSTATION NUMBER	NUMBER UNITS	UNIT CAPACITY	TOTAL CAPACITY
1	5	1500	7500
2	3	1500	4500
3	2	1500	3000
4	3	1500	4500
5	5	1500	7500

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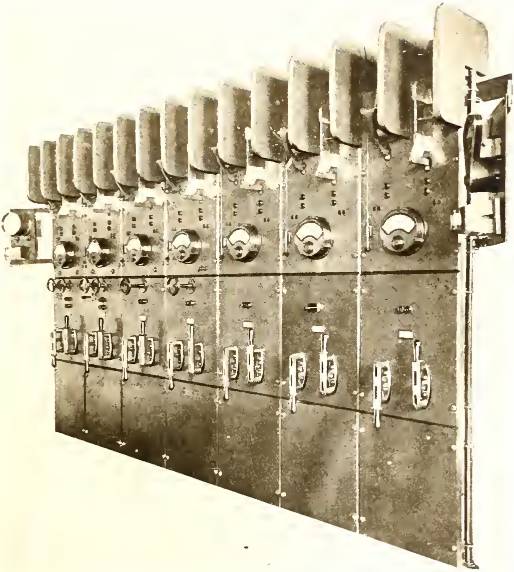
Figure No. 17



1200-VOLT DIRECT CURRENT SWITCHBOARD

G.E. - 222-G 600/1200-VOLT VENTILATED COMMUTATING-POLE RAILWAY MOTOR

The G.E.222-G railway motor is one of the larger sizes of the General Electric Company's new line of ventilated, commutating-pole motors, and is designed to meet the re-requirements of modern, high speed, interurban service and steam line electrification.

The G.E.222-G 600/1200 volt motor has a rated output of 130 H.P. It has, however, a greater service capacity than motors the the closed type having the same hourly rating, because of the special feature of induced ventilation. In these motors there is a definite longitudinal circulation of air through the whole interior of the motor which cools all the interior parts to an extent heretofore impossible.

The General Electric Company recommends the box frame motor in all capacities. Some motors in this line are designed for both full and tapped field operation. The

adoptation of cummutating poles with the resulting improvement in commutation has made practicable the use of field control where operating conditions are such as to warrant the increased complication.

BOX FRAME MOTOR

In the box frame motor, the magnet frame is one piece of cast steel, approximately octagonal in shape. The frame is provided with bored openings at each end. The armature and pole pieces, and field coils, can be inserted or removed through the pinion end opening. Bails are cast on the frame at convenient points to facilitate handling.

The opening through the frame over the commutator is large and inclined at an angle to allow easy access to the commutator and brushholders. Handhole openings are located at points most convenient for the inspection of the interior of the motor. Drain holes are drilled in the lower side of the motor frame.

The axle caps (which are inclined at an angle of approximately 60 degrees to the

horizontal) are tongued and bolted to machined surfaces on the magnet frame.

VENTILATION

The definite air circulation is obtained by means of a fan which is an integral part of the armature core head, in conjunction with longitudinal ducts through the interior of the commutator and armature. The result is the elimination of hot spots in the windings. Such hot spots were usual in designs with radial armature ducts.

The pinion end frame head of this motor is provided with an annular ring which diverts the air discharge from the armature fan through the openings in the head, while the incoming air is drawn through a screened intake.

If it is desired to operate the motor as a closed motor, solid covers and frame heads are used with a box frame motor and a different form of frame with the split frame motor. In this case there are no ventilation openings to the outside air, and the air is circulated

internally in the motor. Even when operated entirely closed this type of motor has the advantage of increased capacity and reduced maintenance owing to the positive and effective circulation of air and the elimination of hot spots in the windings.

ARMATURE AND WINDINGS

The armature core is built up of laminations mounted upon and keyed to the armature shaft. The armature is so constructed that the shaft can be removed without disturbing the windings or connections to the commutator. The laminations are punched and are assembled with the holes in alignment so as to provide longitudinal holes through the core structure. The absence of radial ducts gives a rigid construction permitting high assembly pressure and insuring tight cores. With this construction the cummutator and windings are completely shrouded on the under side of the windings, insuring freedom from dirt to which a structure with radial ventilating ducts is exposed. The armatures after being

heated are bound with temporary steel bands which force the coils tight in the slots. After the armatures are cooled the permanent bands are put in place, thus insuring tight bands and freedom from loose coils.

The armature shaft is made of high-grade material and the bearings' surfaces are ground and rolled, giving an excellent wearing surface and insuring maximum lift of bearings and shaft.

POLE PIECES

Exciting pole pieces are built of laminations mounted on a steel key into which tap bolts are inserted for bolting the poles to the magnet frame. The commutating pole pieces are made of drop forged steel, and are held in place by means of tap bolts. The commutating pole pieces have pole tips forged integral with them for holding the coil in position.

FIELD COILS AND SUPPORTS

The field coils are all wound with strap copper and are insulated between turns

with strip asbestos. Each coil is mummified and insulated with varnished cambric and further protected by a strong and durable tape. The coils are clamped between pressed sheet steel coil seats and angle springs held by the pole piece tips. This arrangement insures a distributed pressure on the coil, and holds the coil away from the frame; the angle springs prevent movement in any direction. Field lead terminals support the cable beyond the soldered portion, thus preventing broken leads. This is accomplished by means of a ferrule which extends well back under the insulation.

ARMATURE BEARINGS

The armature bearing linings are made of bronze with a layer of babbitt sweated to the shell. The thickness of the babbitt is such that should the babbitt be melted away by overheating, the shaft will be supported by the bronze sleeves, preventing the armature striking the pole piedes. Oil and waste are used for lubrication; the waste is held against

the low pressure side of the shaft. Oil is prevented from entering the interior of the motor by a series of oil deflectors which throw it into grooves in the frame heads, from which it passes to the drip pockets.

HIGH TENSION VOLTAGE FOR TRANSMISSION

From figures compiled by Mr. Dodd (railway engineer of the General Electric Co.) the total power requirements of all the railroads in the United States - if operated electrically - would only be about one third of the present generating capacity of the central stations in the United States. Figured on a smaller basis - the "Super power zone" on the Atlantic seaboard - the same ratio was obtained. Mr. Ferguson of the Commonwealth Edison Co. of Chicago, in quoting some figures from the Smoke Abatement report* made the statement that the total power requirements to electrify all the railroad terminals in Chicago would be about one-third of the present generating capacity of the Commonwealth Edison Co. The Illinois Central railroad being only one of a number of railroads terminating in Chicago would offer no real difficulties to the local power company as far as power for electrification is concerned. Out of 45 railroads in the United States using high tension direct current, 33 of

them or 73 per cent purchase their power. The interest and maintenance, etc. on a new investment at present would be such as not to warrant the expenditure for a new power plant. In view of the present conditions, we deem it advisable to buy power from the Commonwealth Edison Company. Therefore the equipment chosen will be standard and interchangeable with C.E. Co. equipment so as to reduce interruption of service to a minimum.

The standard high tension voltages used for transmission in Chicago are:

12,000 volts - 60 cycles
6,600 volts - 60 cycles
9,000 volts - 25 cycles
20,000 volts - 25 cycles

As synchronous converters for 25 cycles have been standardized for larger capacities and in general give better operating characteristics than the 60 cycle machines and are standard for Chicago railway equipments, 25 cycle current will be considered exclusively. As I^2R losses and

weight of copper in transmission lines decrease as the voltage increases, 20,000 volts will be used for the transmission line between the substations. The increased cost of insulation, switches, transformers, etc. is more than offset by the saving in heat losses and copper. The transmission line will follow the tracks on the trolley poles as shown in figures (45) and (46).

* Smoke Abatement and Electrification of Railway Terminals in Chicago.

FEEDERS

The trolley which consisted of 4/0 wire is reinforced between the substations with two 500,000-C.M. bare copper cables tapped to the trolley at intervals of 1000 feet. This wire is carried on the trolley poles and at intervals of 1000 feet it is connected to the cross bonds. The rails are connected at every point by 4/0 bonds. By means of these feeders the substations are normally connected together, thus allowing an interchange of current. In emergency either station can supply current to the entire system.

OVERHEAD CONSTRUCTION

The overhead construction for this system is to be designed to give maximum flexibility for operation of the pantograph trolleys used on the locomotives. The 4/0 grooved copper trolley wire used over all tracks is supported by an eleven-point,

catenary suspension from a stranded steel messenger cable. The side brackets and cross span construction are selected so as to satisfy local conditions. There is a large amount of special work on account of the many yards and sidings. The cross span construction used throughout the yards is supported by means of poles between every sixth track. The hanger used on the straight line construction is a rolled steel, strap looped over the messenger wire. This loop is closed at the car and the wire is clamped in place by a single bolt. Special pull-offs are used to increase the flexibility of the suspension.

The section breakers were designed for the 1200 volt service. On the main line a very simple section insulator is used. This consists of paralleling the two trolley wires from the ends of each section at

a suitable distance for insulation so that the pantograph bridges the two circuits for a short distance, thus avoiding interruption of the power supply to the locomotive. The construction in the yards and sidings is simplified by paralleling the trolley from the side tracks for a short distance along the main line. This does away with the use of switch plates or similar devices.

The uniformly successful operation of this overhead work is largely due to its very simple and flexible construction and the absence of frogs at meeting points.

The overhead lines are protected from lightning by 1200 volt direct current TYPE ME arresters installed on poles at intervals of one-third of a mile the entire length of the system.

COLLECTION OF CURRENT

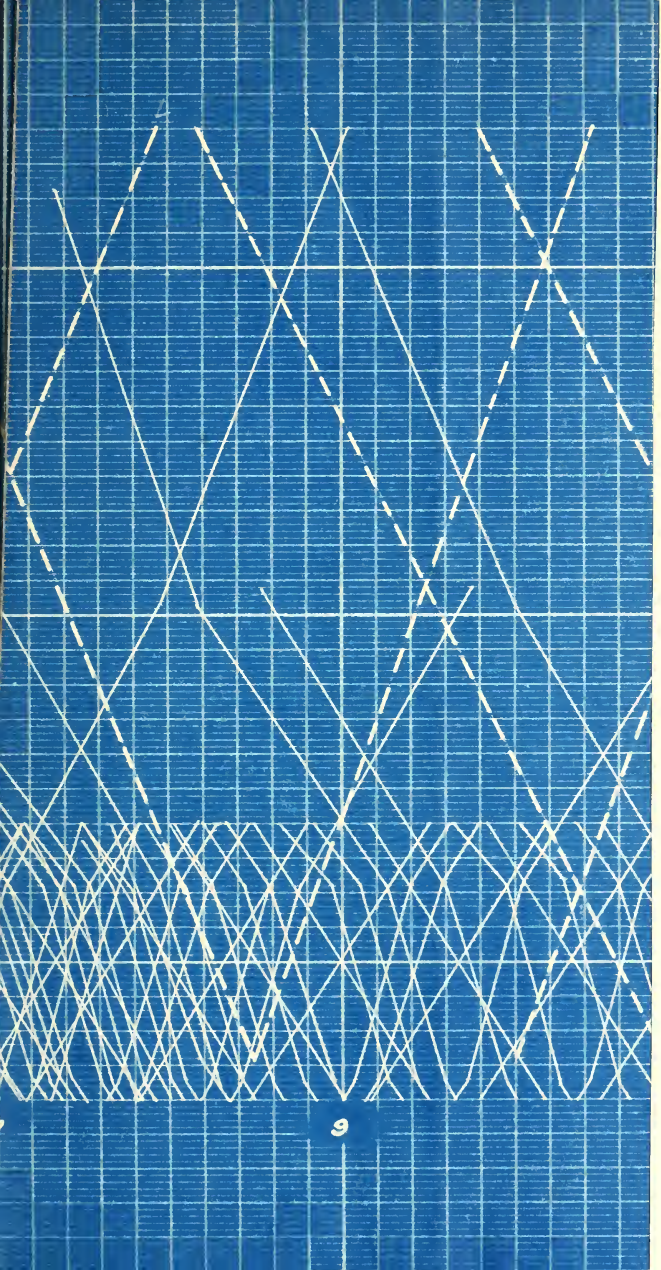
The trolley pole and wheel which has so well served the electric railway is not well adapted for the heavy service we have been considering, nor is it a convenient device for movement in both directions. The pantograph collector which requires no attention on reverse movement has long been used, but it is only within the last few years, that its capacity as a collecting device has been fully demonstrated. Rolling and sliding contacts have both been tried with results distinctly in favor of the slider. The wear of the working conductor, or trolley wire, is due far more to the distruction by arcs at the point of contact than from the mechanical friction, hence it is most important that the wire be so supported as to eliminate any rigid spots which are the usual cause of this arcing. The wire should be lifted slightly and really supported by the collector rather than the collector should run underneath a wire held in rigid re-

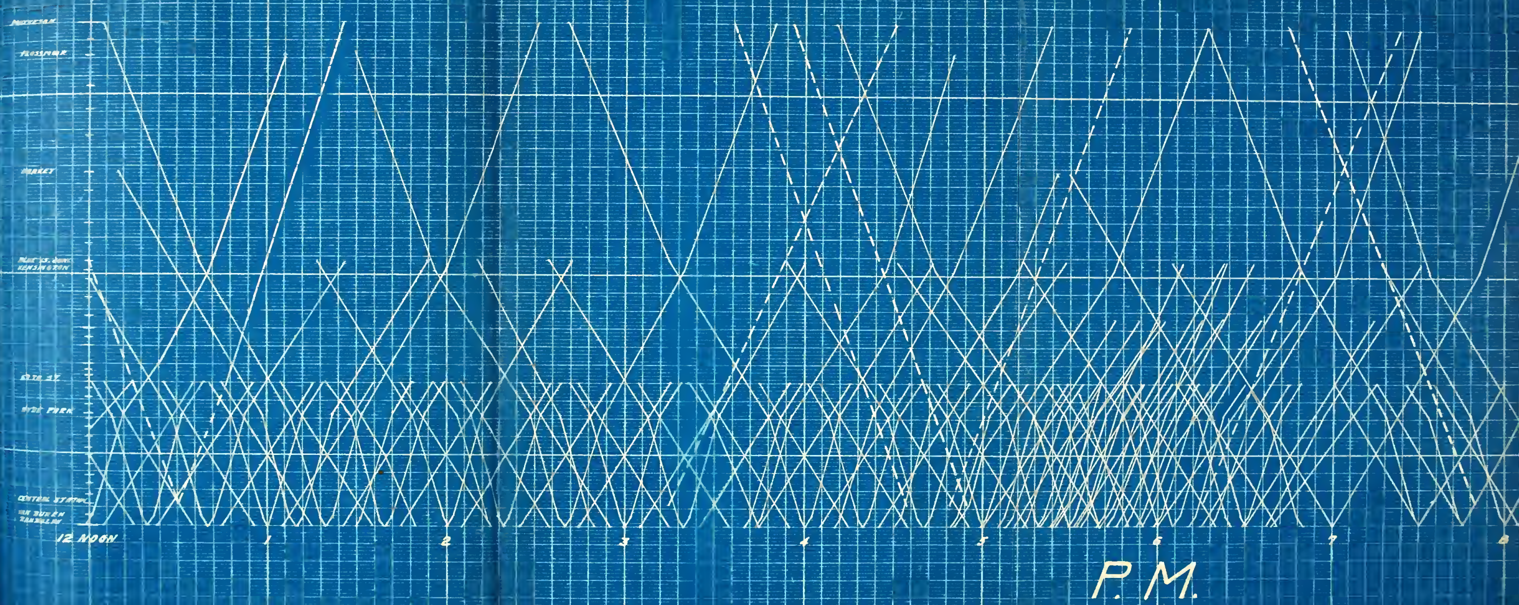
lation to its support. Lubrication of the collecting surface not only reduces the wear but seems to slightly improve the contact, presumably because of less tendency to chatter than with bare metal. The amount of current that can be successfully collected seems limited only by the current capacity of the working conductor. Tests have shown no arcing at the contact with 3000 amperes at 30 miles, and 2000 amperes have been collected with equal success at over 60 miles per hour. A copper conductor with copper wearing strips on the collector has been found to give the best results. Measurements taken on the Chicago, Milwaukee & St.Paul Railroad indicate the working conductor will have a life of over 100 years before it will have to be replaced because of wear.

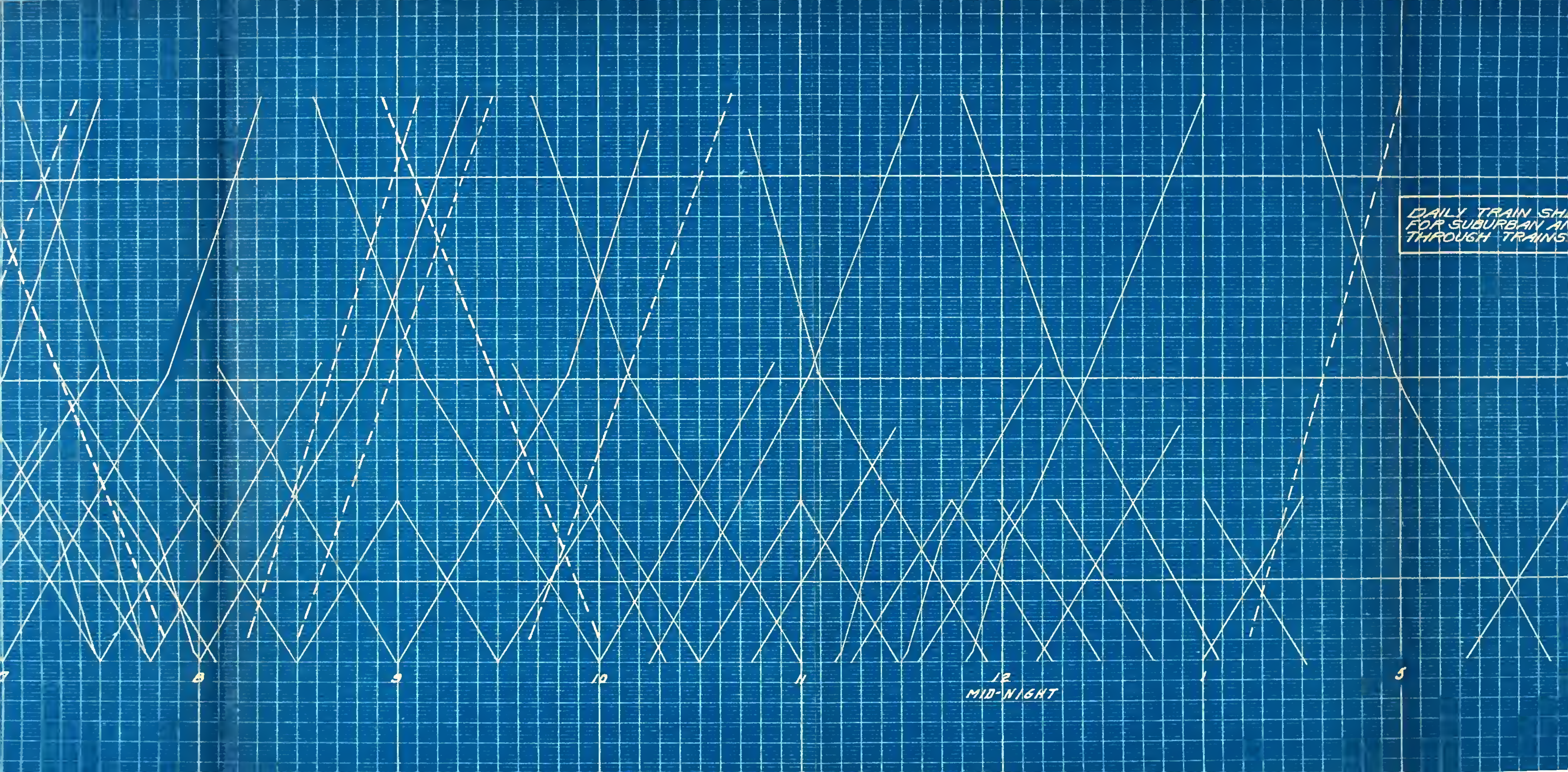
RAIL BONDING

CROSS BONDING: Thus far the bonding of rail ends alone has been considered. It is sometimes necessary to provide against the greatly increased resistance of the return circuit due to a possible pen bond by connecting the rails together electrically by means of cross-bonds spaced several hundred feet apart. These usually consist of bare copper wire of approximately the size of the bonds soldered to the bonds on opposite rails or to special single headed bond terminals forced into the rail web. Thus if a bond be opened, the return current on that particular rail would follow the nearest cross-bond to the other rail and find its way back to the original rail at the next cross-bond nearest the power station.

As the bonding of all joints in special work such as switches, cross-overs, and frogs would often involve a large number of bonds, a heavy cable is often laid around such portions of the track and thoroughly bonded to the sections of track on either side thereof.


9


MATTESON
FLOSSMOOR
HARVEY
BLUE IS. JUNC.
KENSINGTON
67TH ST.
HYDE PARK
CENTRAL STATION
VAN BUREN
TERMINAL
12 NOON
1
2
3
4
5
6
7
8
P.M.


DAILY TRAIN SH
FOR SUBURBAN A
THROUGH TRAINS
7
8
9
10
11
12
MID-NIGHT
1
5

Electrification of the
Illinois Central Railroad Terminal
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Figure No 2A.

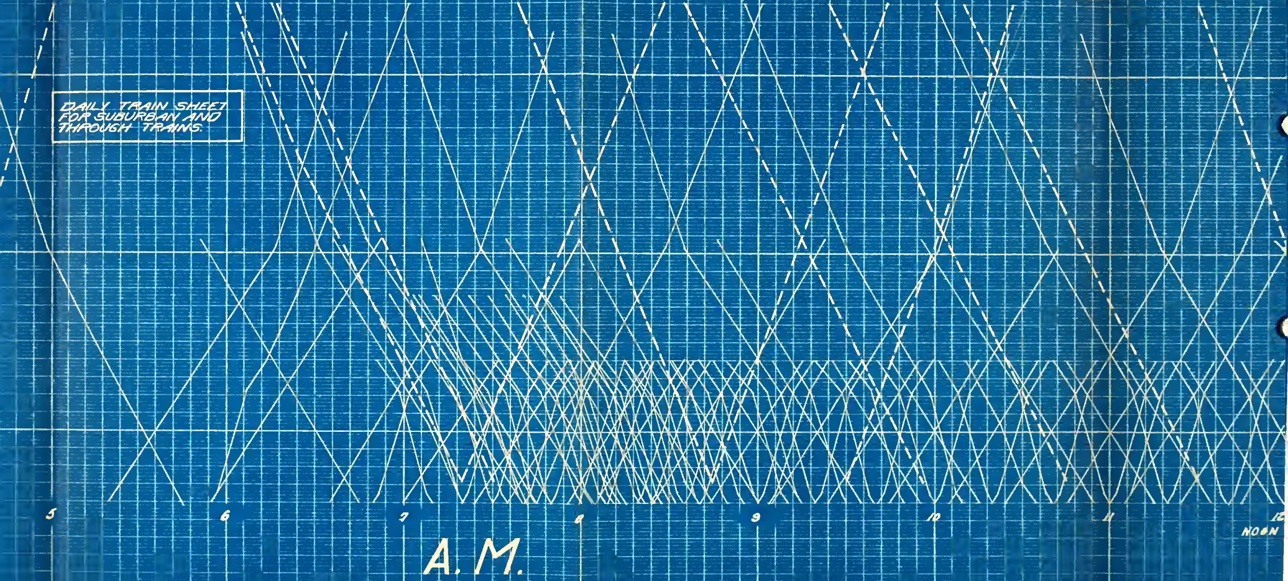

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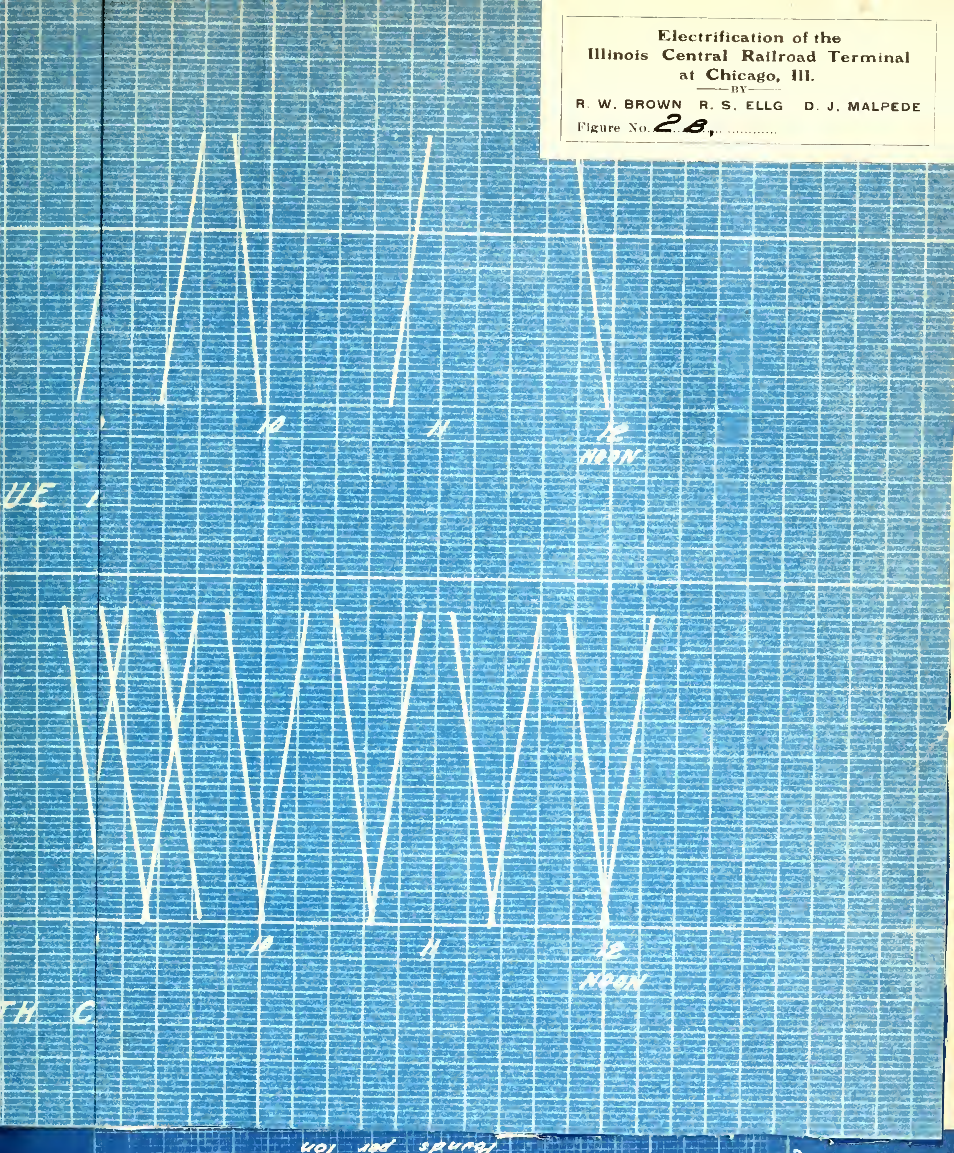
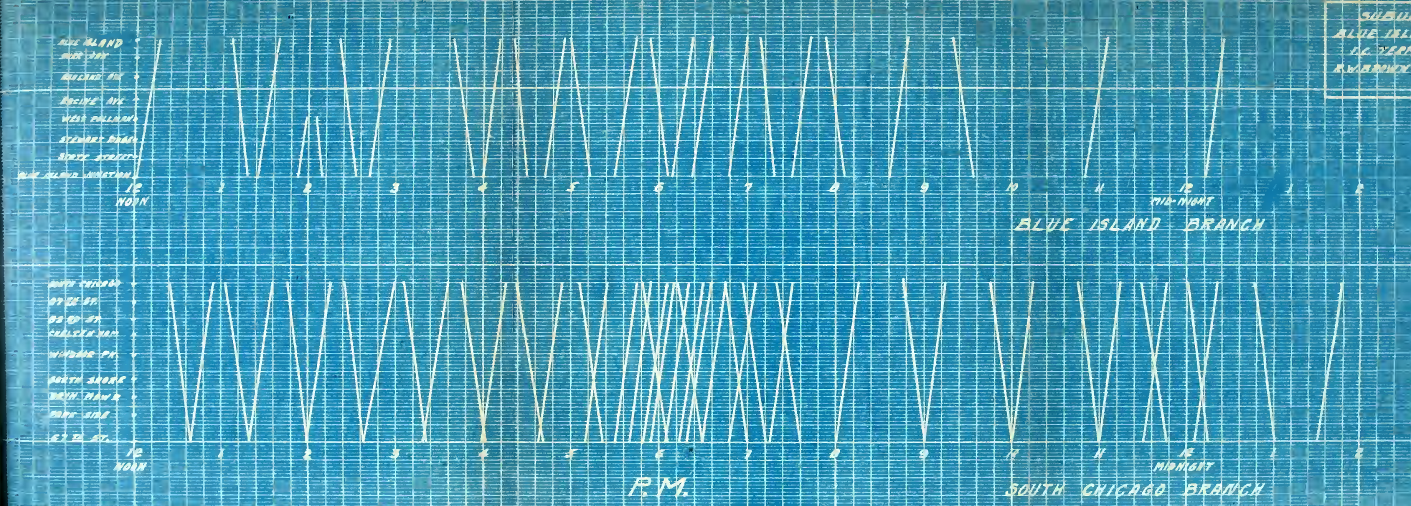
Figure No. 2 B.



SUBU
BLUE ISL
I.C. TERR
R.W.BRNWY
BLUE ISLAND
BURR OAK
ASHLAND AVE
RACINE AVE
WEST PULLMAN
STEWART RIDGE
STATE STREET
BLUE ISLAND JUNCTION
12 NOON
1
2
3
4
5
6
7
8
9
10
11
12 MID-NIGHT
1
2
BLUE ISLAND BRANCH
SOUTH CHICAGO
87TH ST.
83RD ST.
CHELTENHAM
WINDSOR PK.
SOUTH SHORE
BRYN MAWR
PARK SIDE
67TH ST.
12 NOON
1
2
3
4
5
6
7
8
9
10
11
12 MIDNIGHT
1
2
P.M.
SOUTH CHICAGO BRANCH

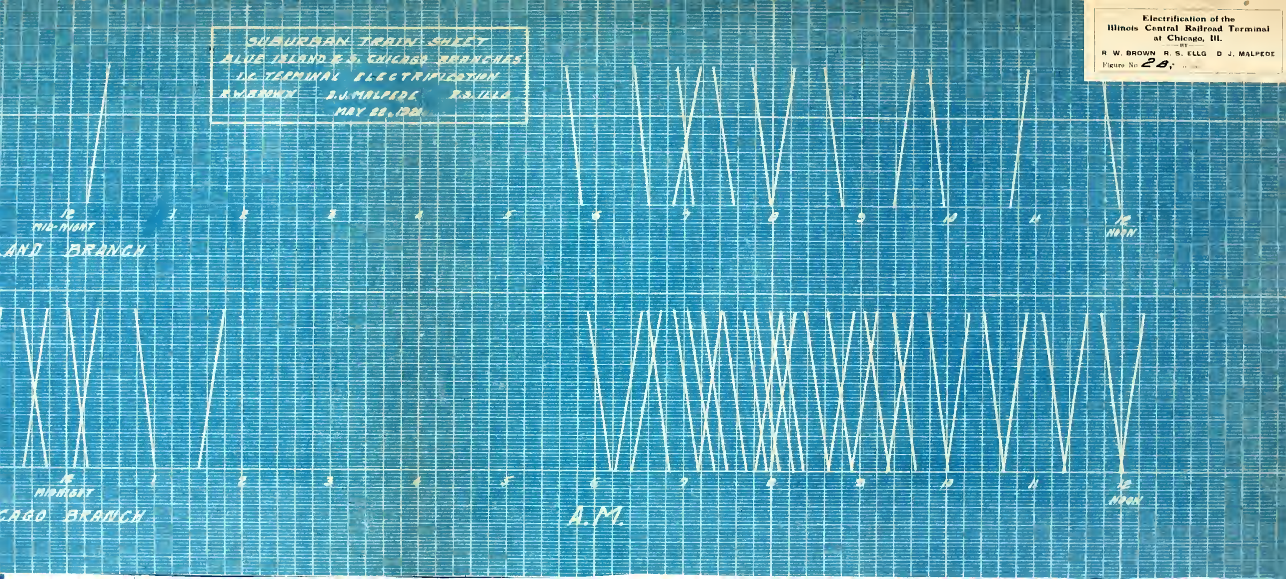


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Figure No 2B,

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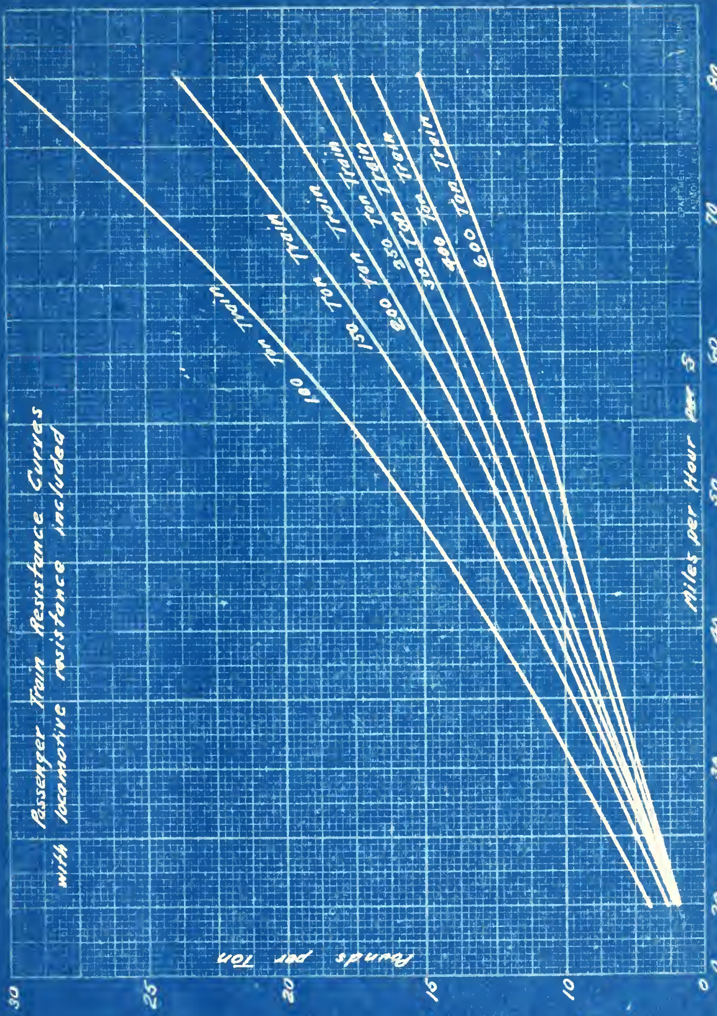
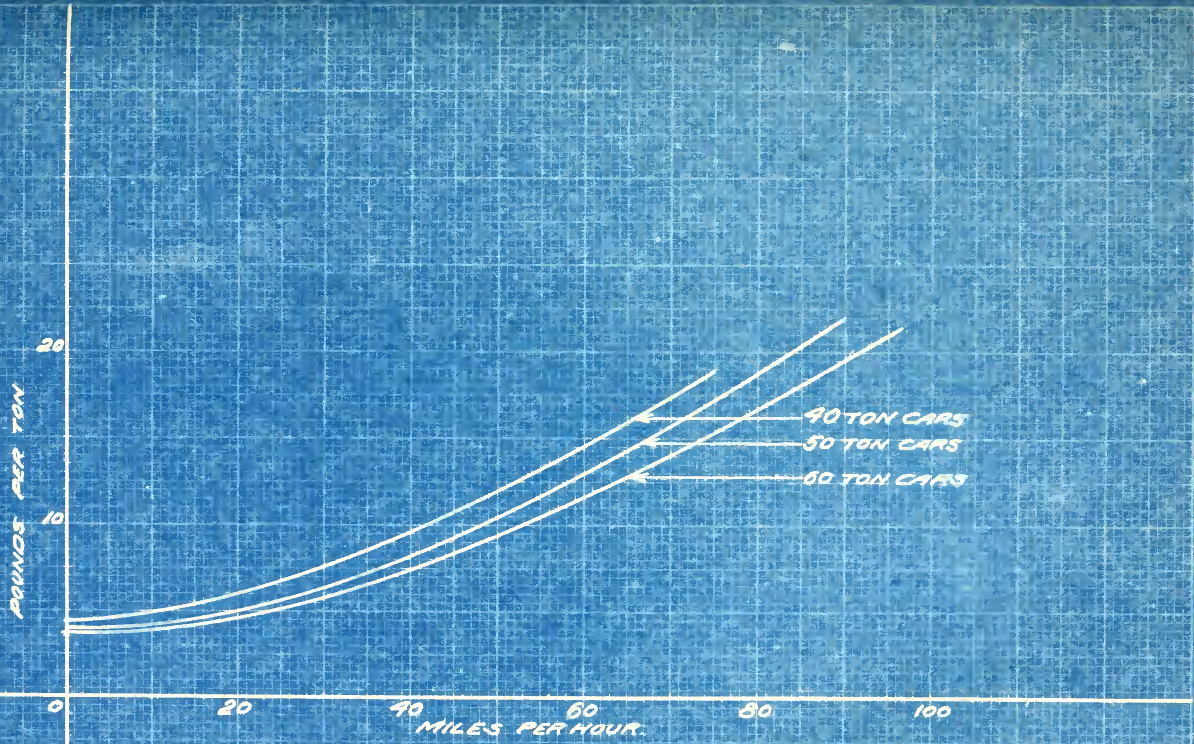
Figure No. 3





TRAIN RESISTANCE 3CAR TRAIN (ARMSTRONG FORMULA) RICHEY E.RY. PAGE 158.

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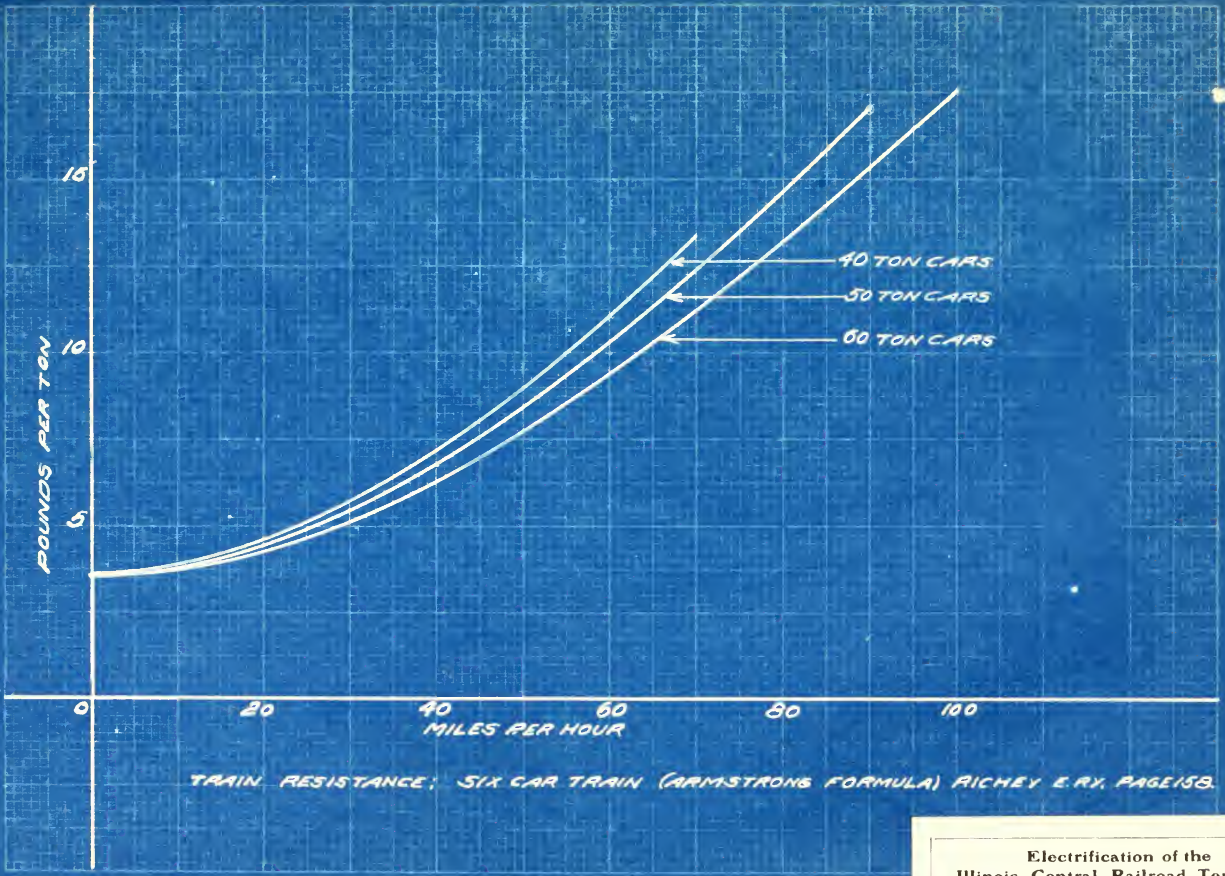
Figure No. 4



TRAIN RESISTANCE: SIX CAR TRAIN (ARMSTRONG FORMULA) RICHEY E.RY. PAGE 158.

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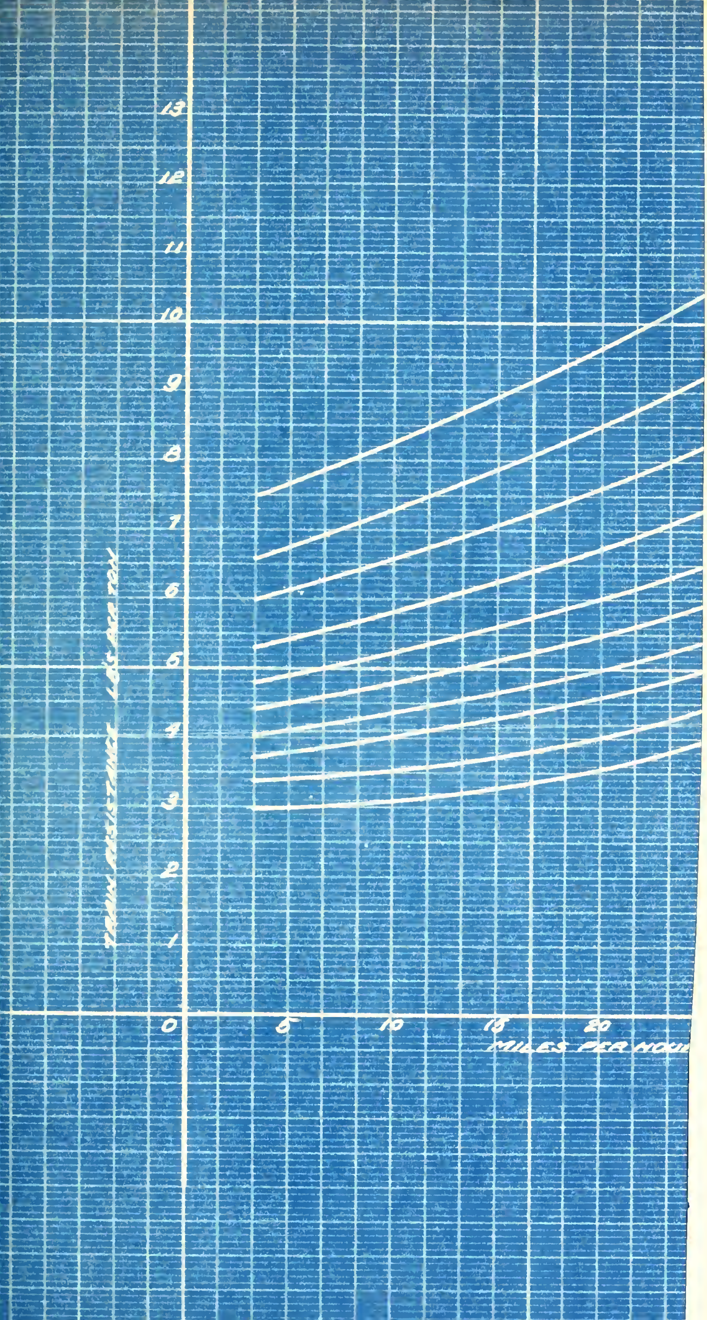
Figure No. 5


13
12
11
10
9
8
7
6
5
4
3
2
1
0
TRAIN RESISTANCE LBS PER TON
5
10
15
20
MILES PER HOU

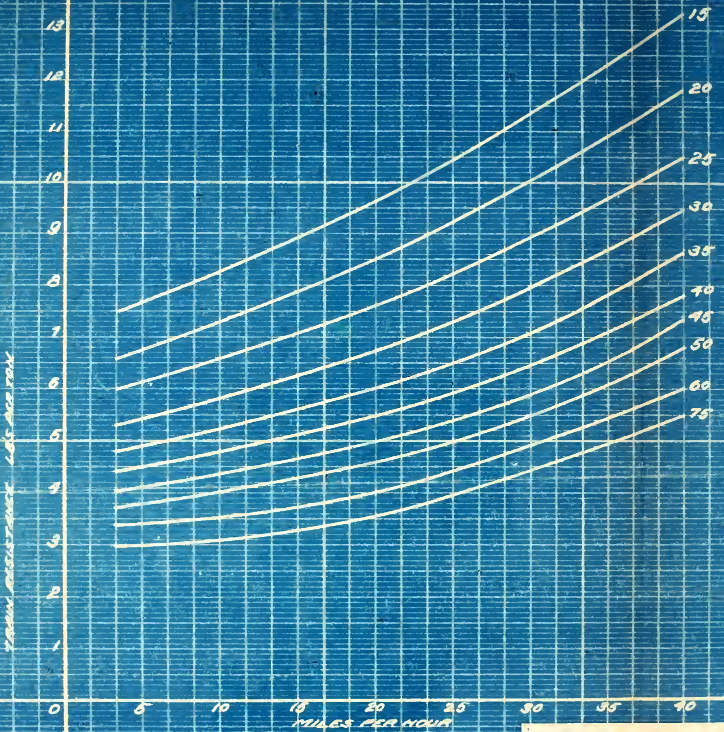


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Figure No. 7

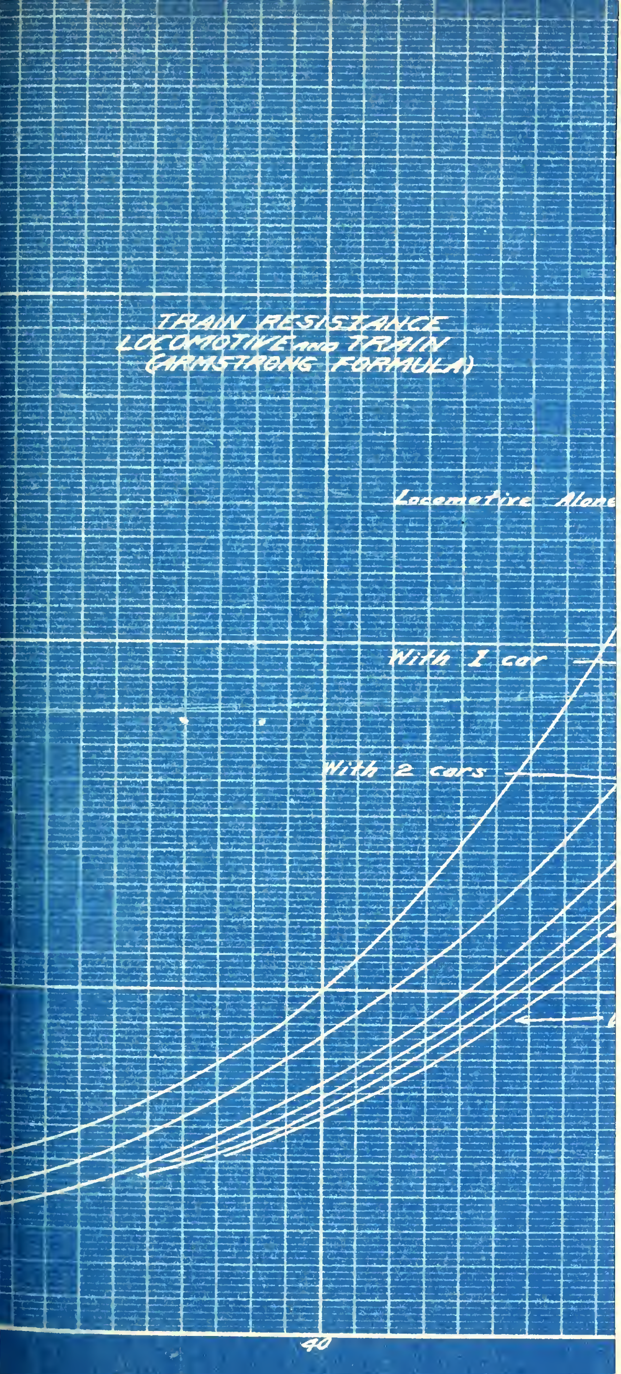
TRAIN RESISTANCE
LOCOMOTIVE and TRAIN
(ARMSTRONG FORMULA)
Locomotive Alone
With 1 car
With 2 cars
40

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Figure No. 6

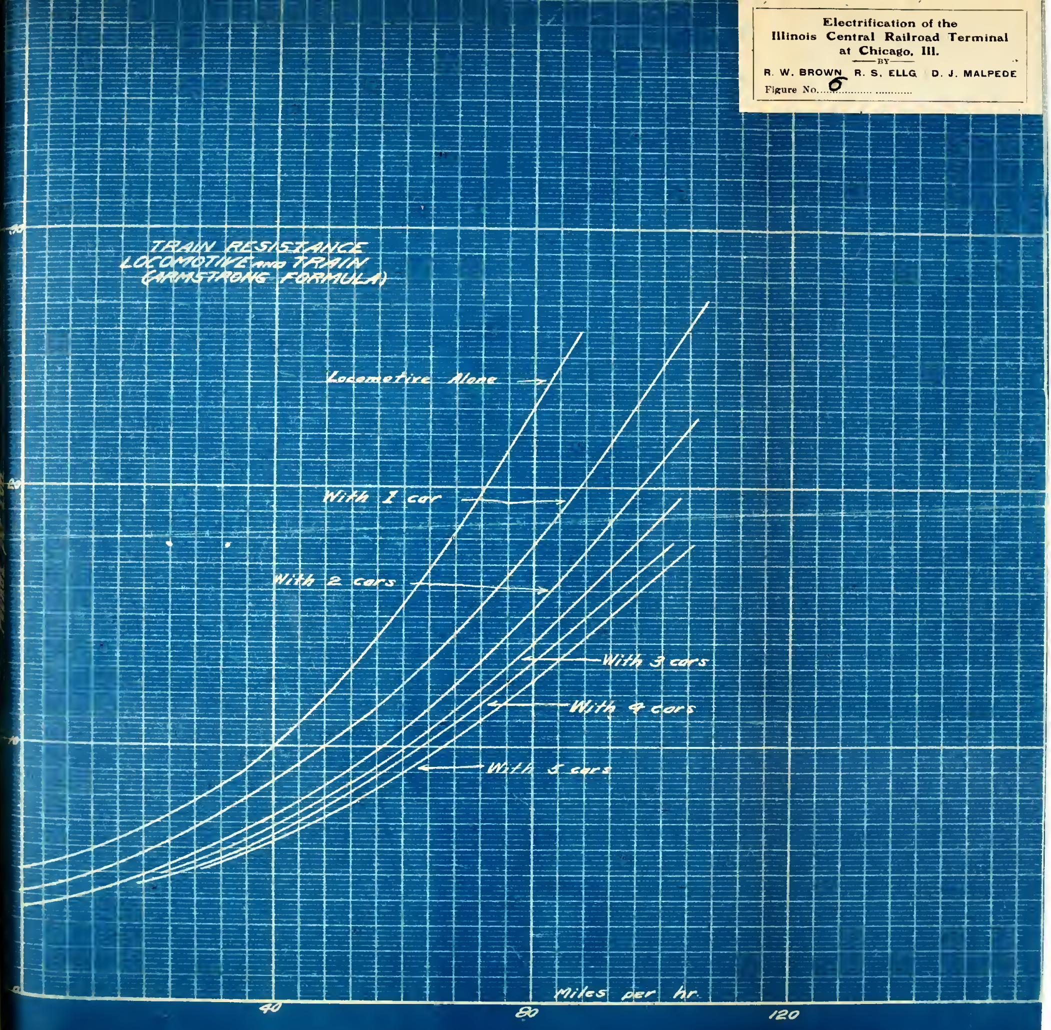

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Figure No. 8

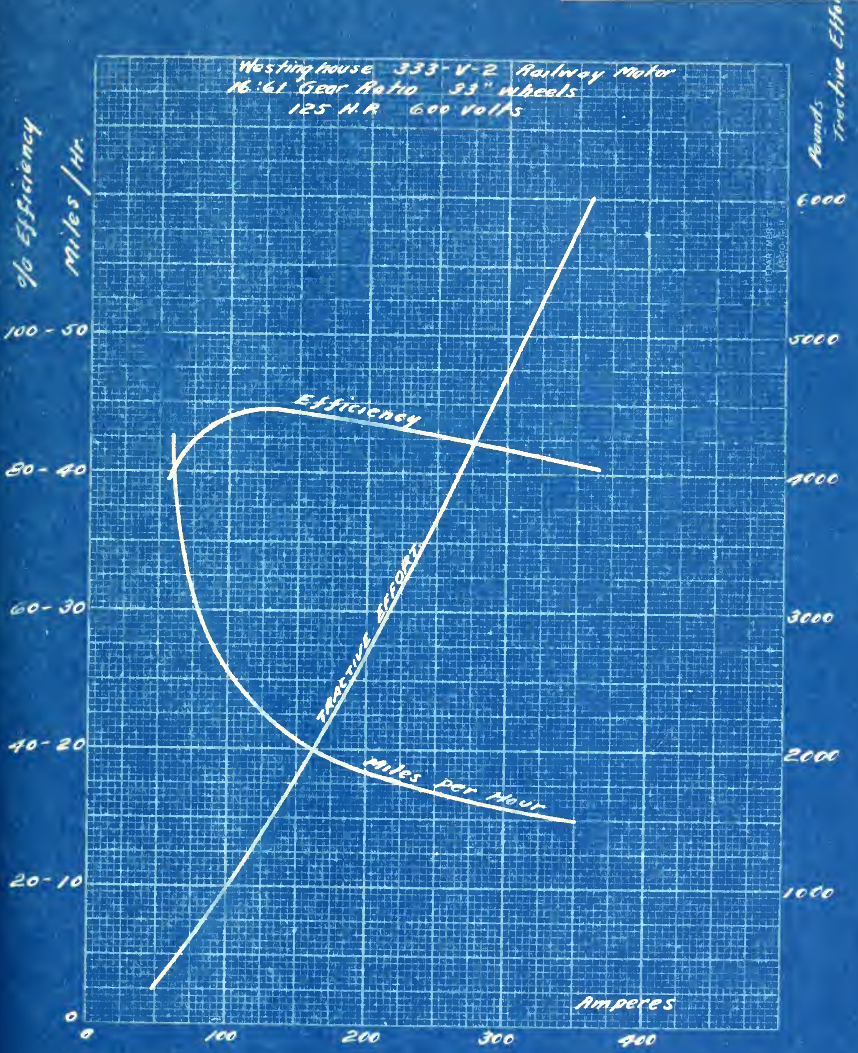

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Figure No. 9

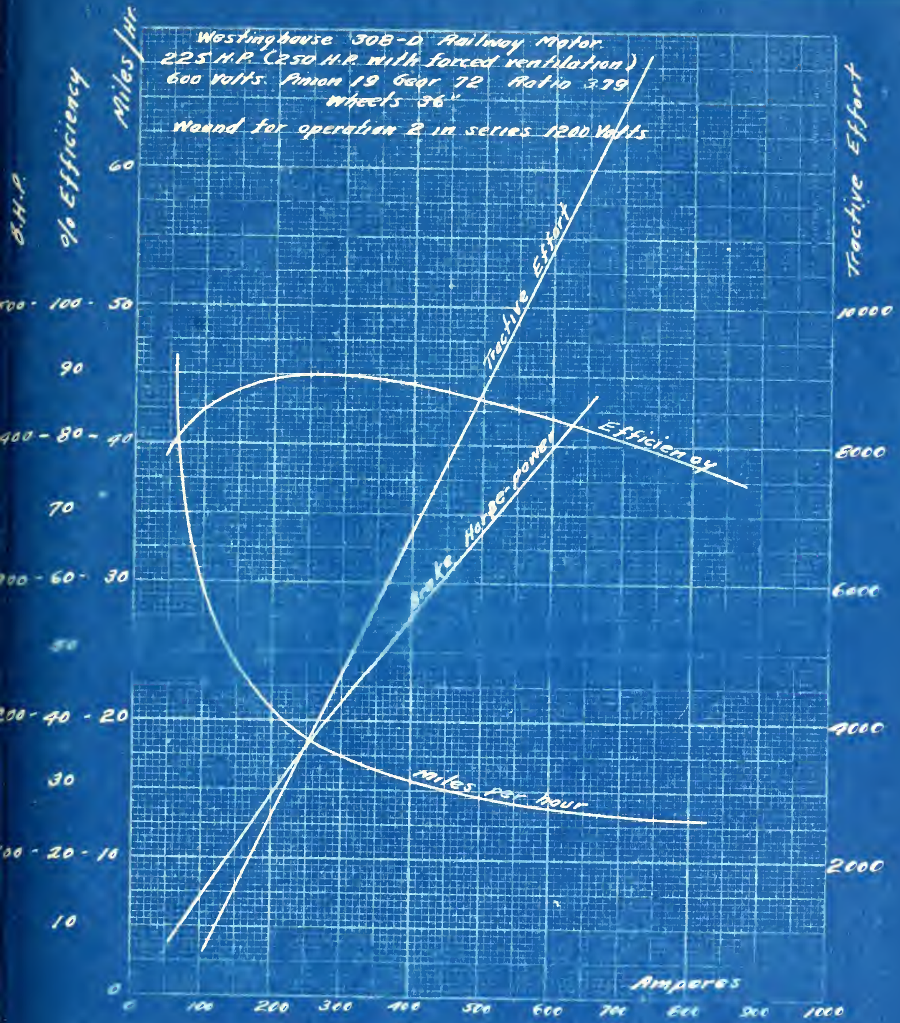

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Figure No. 10

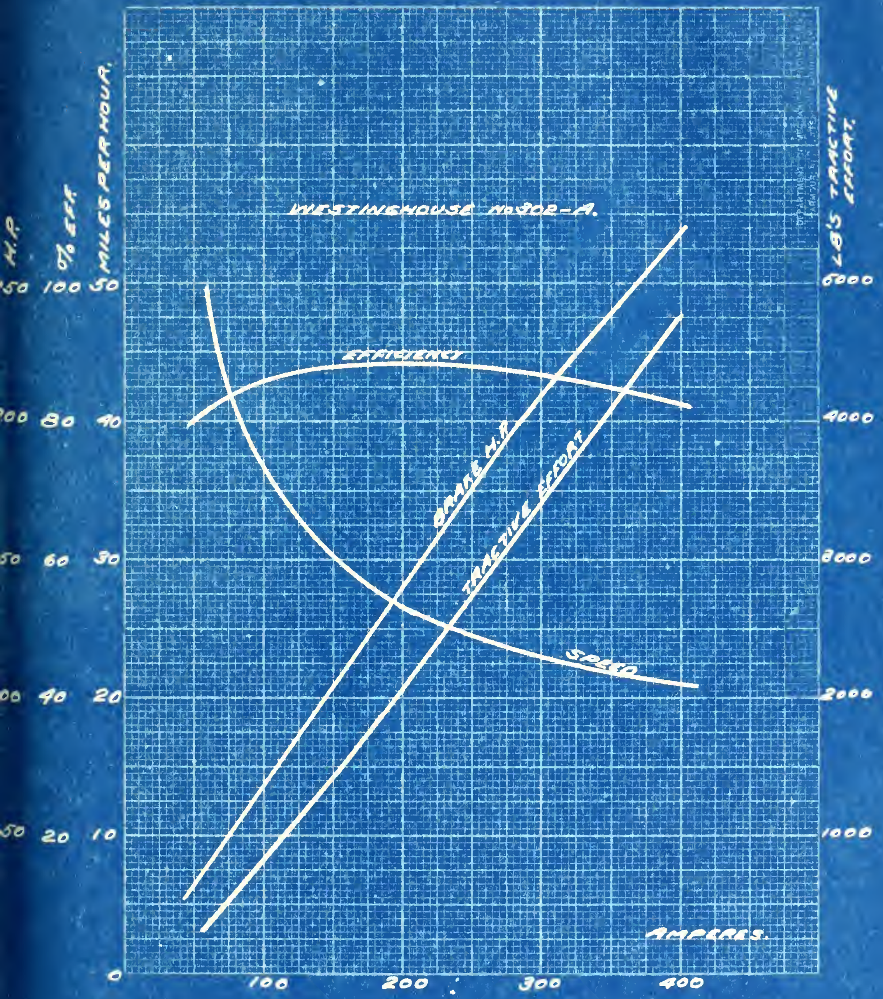

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Figure No. 11

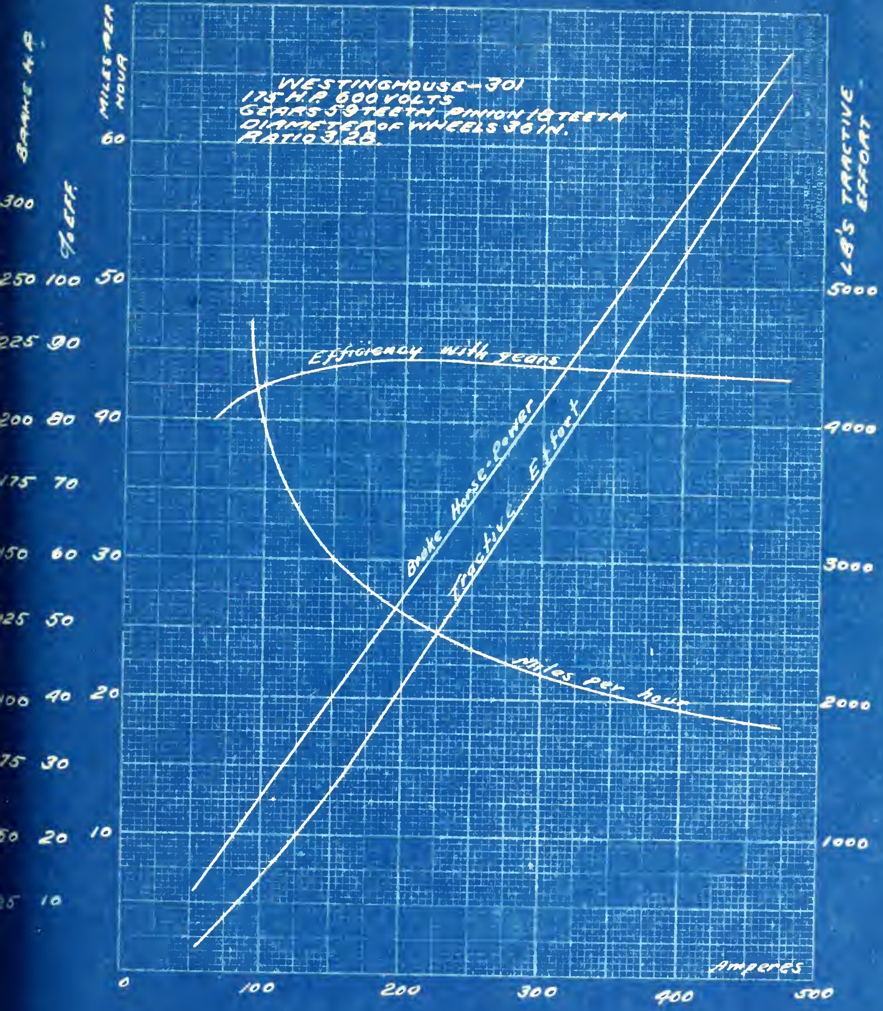

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Figure No. 12

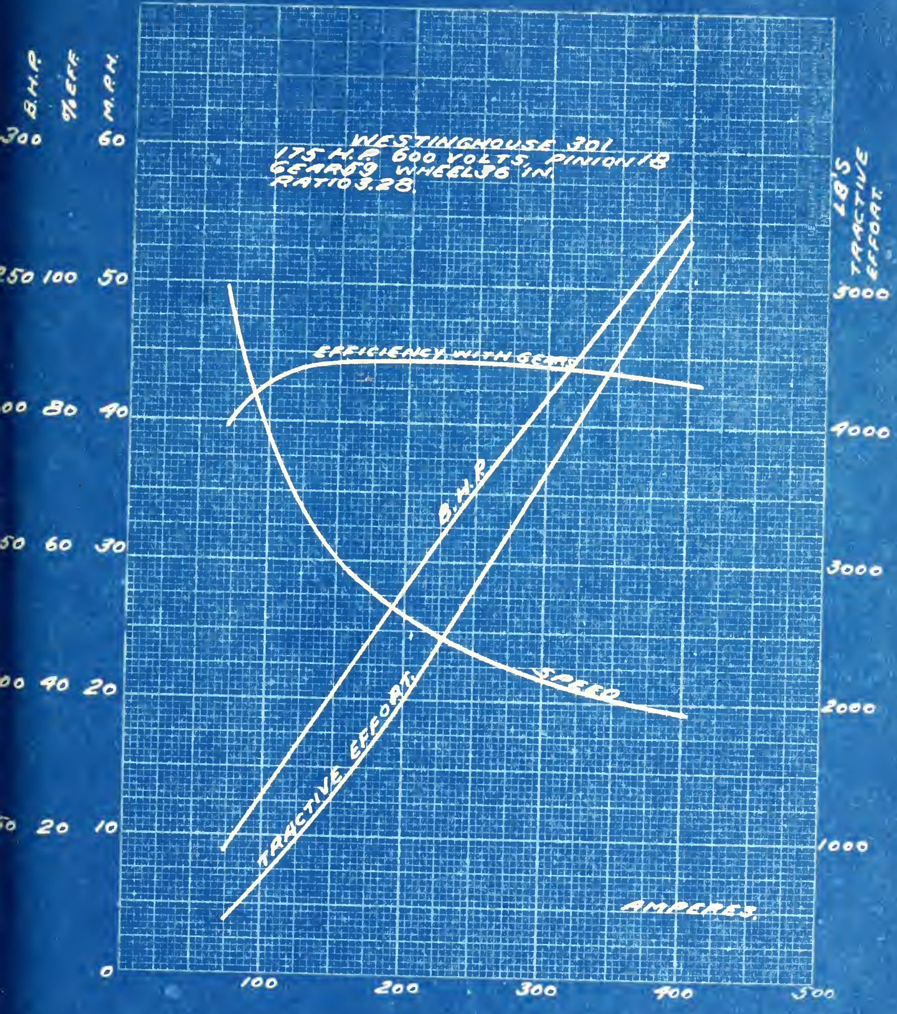

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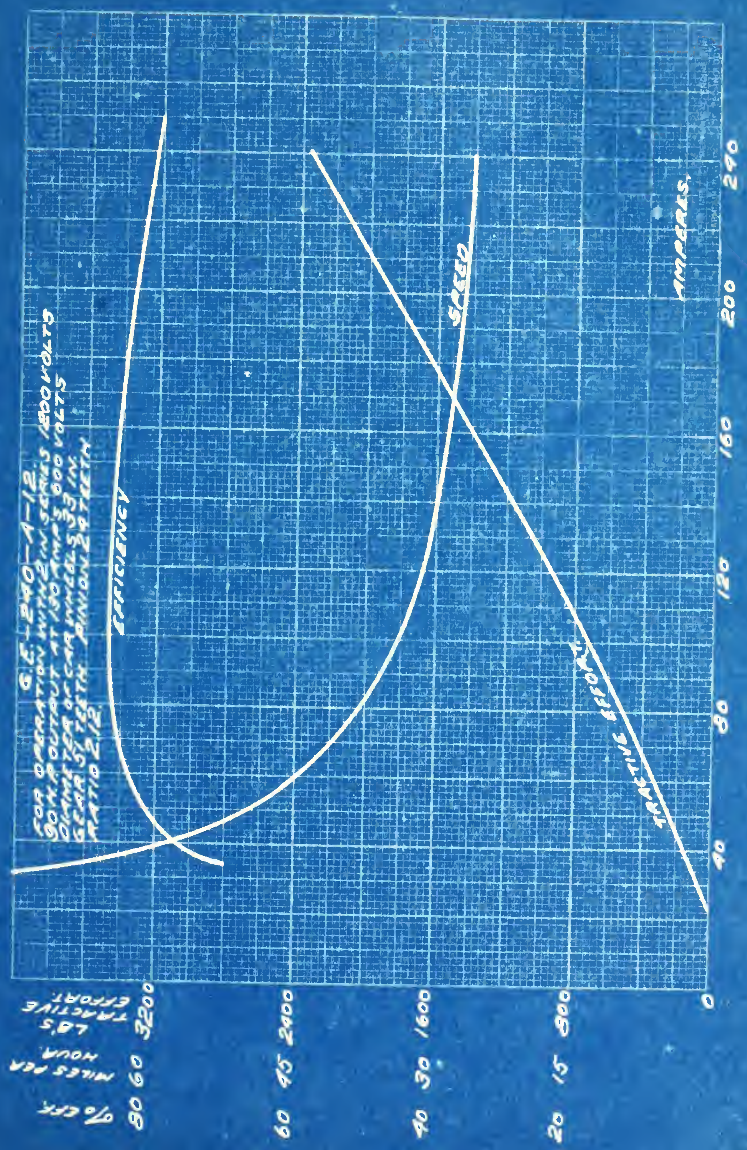
Figure No. 13



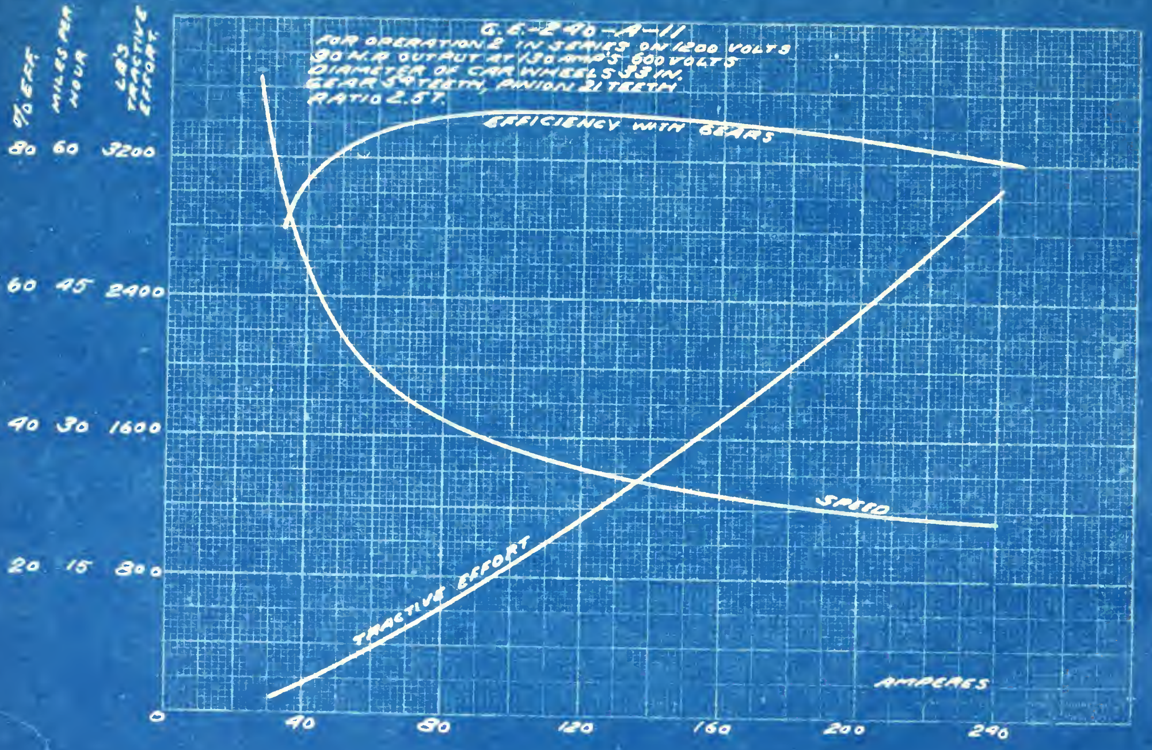


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Figure No. 14

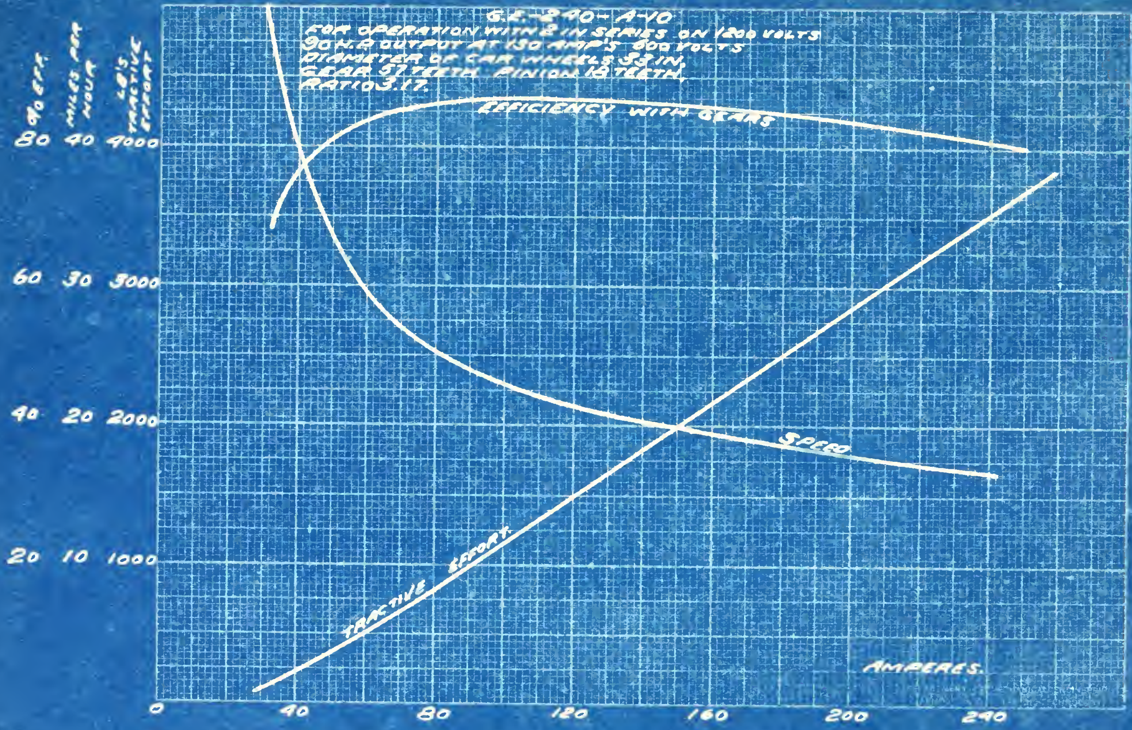

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Figure No. 15

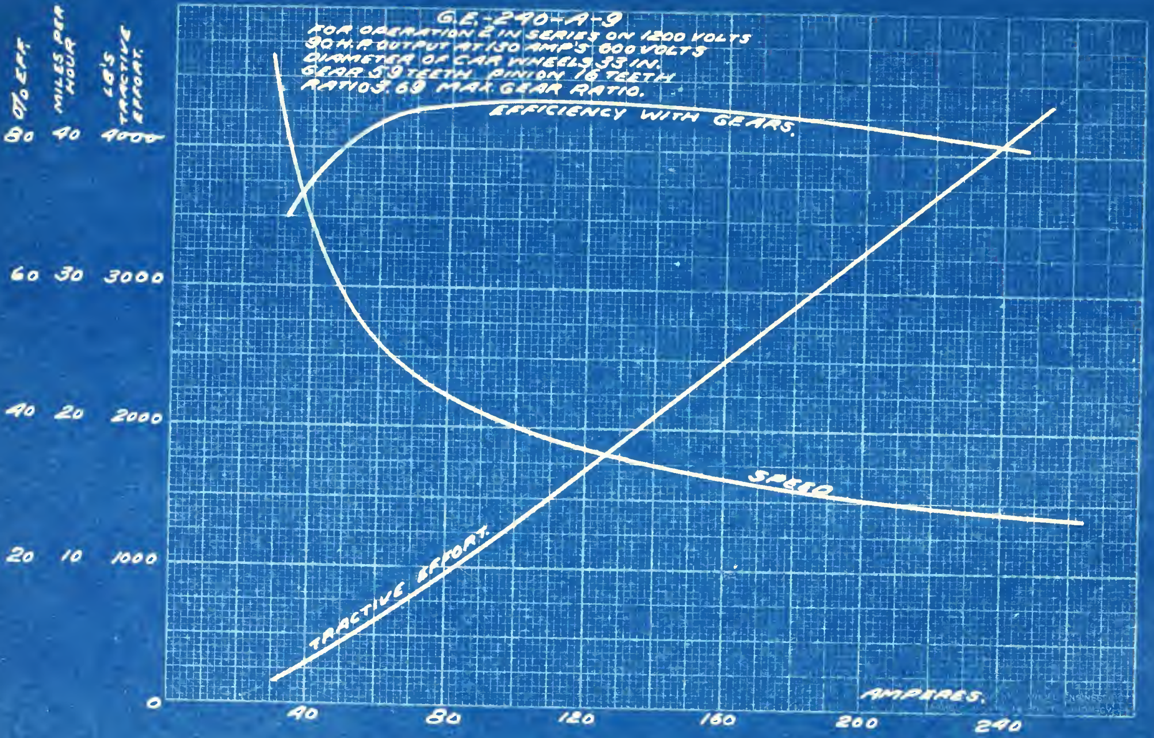

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Figure No. 16

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Figure No. 17

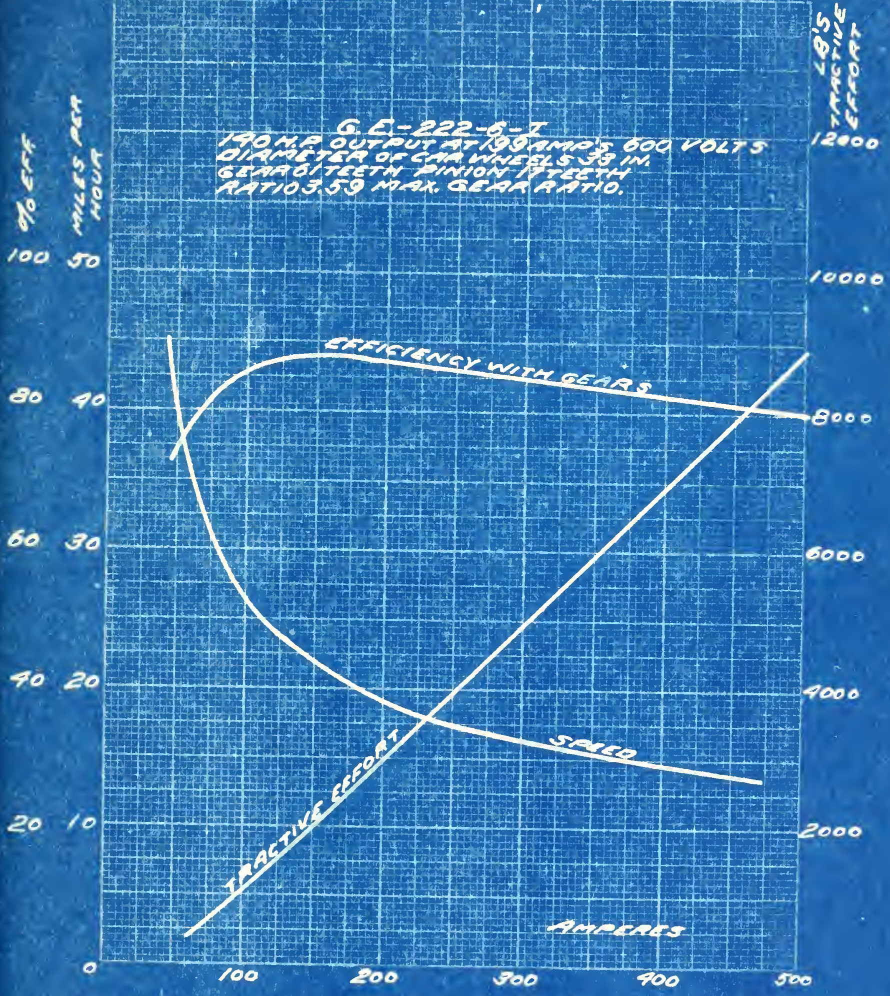

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Figure No. 18

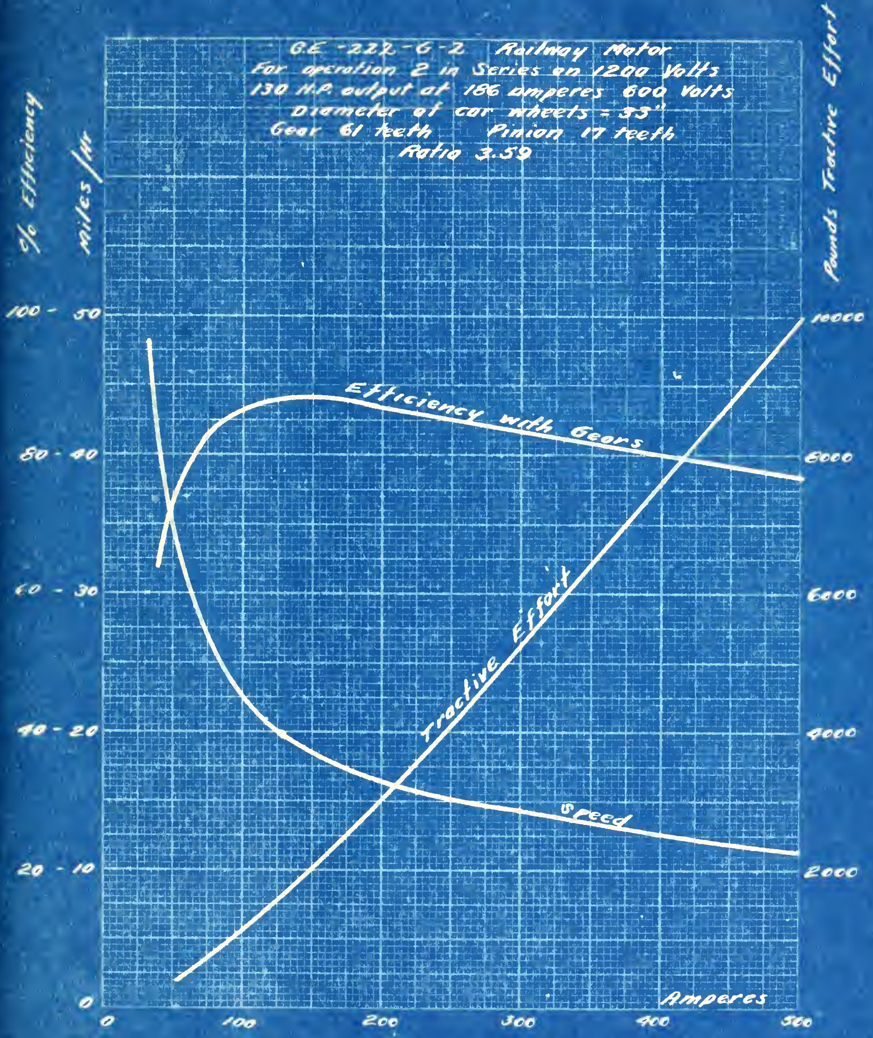

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Figure No. 19

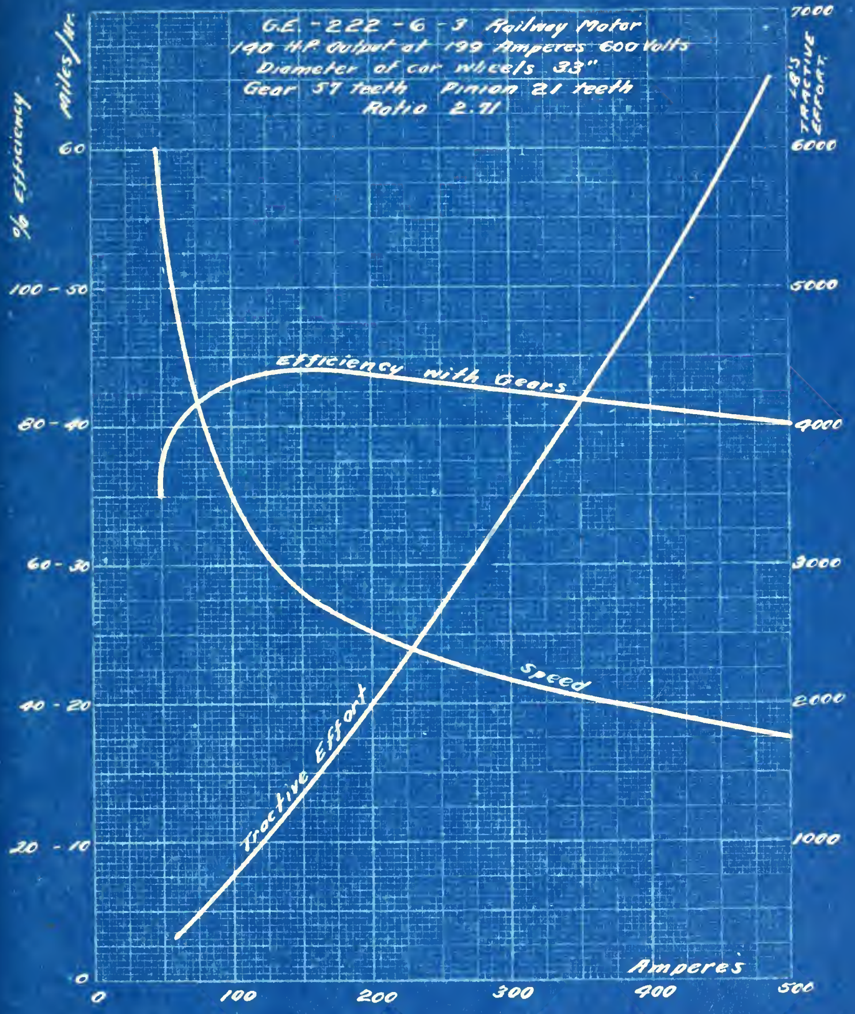

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Figure No. 20

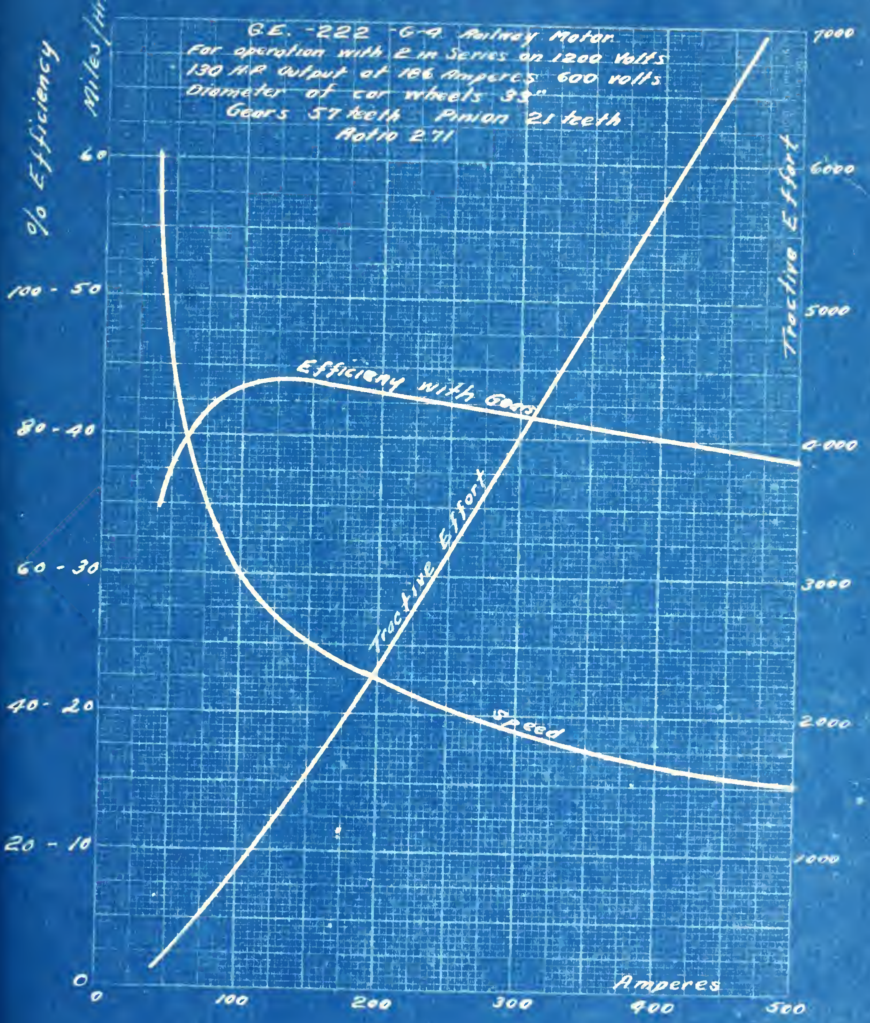

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Figure No. 21

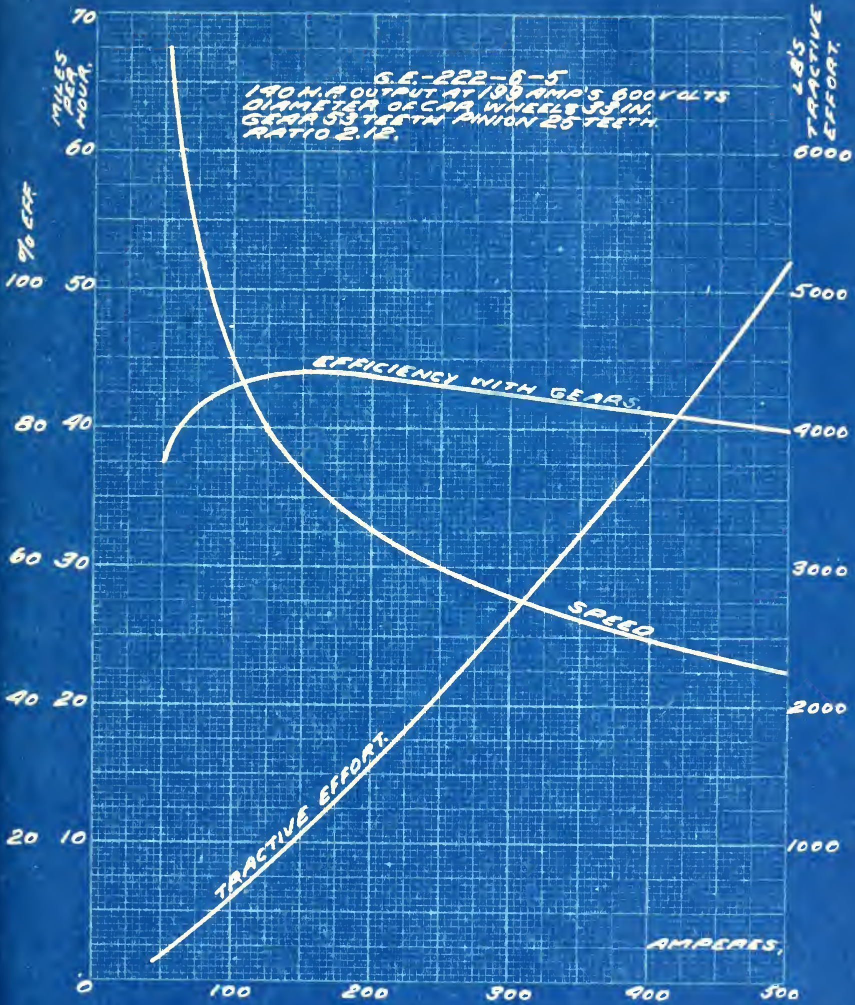

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Figure No. 22

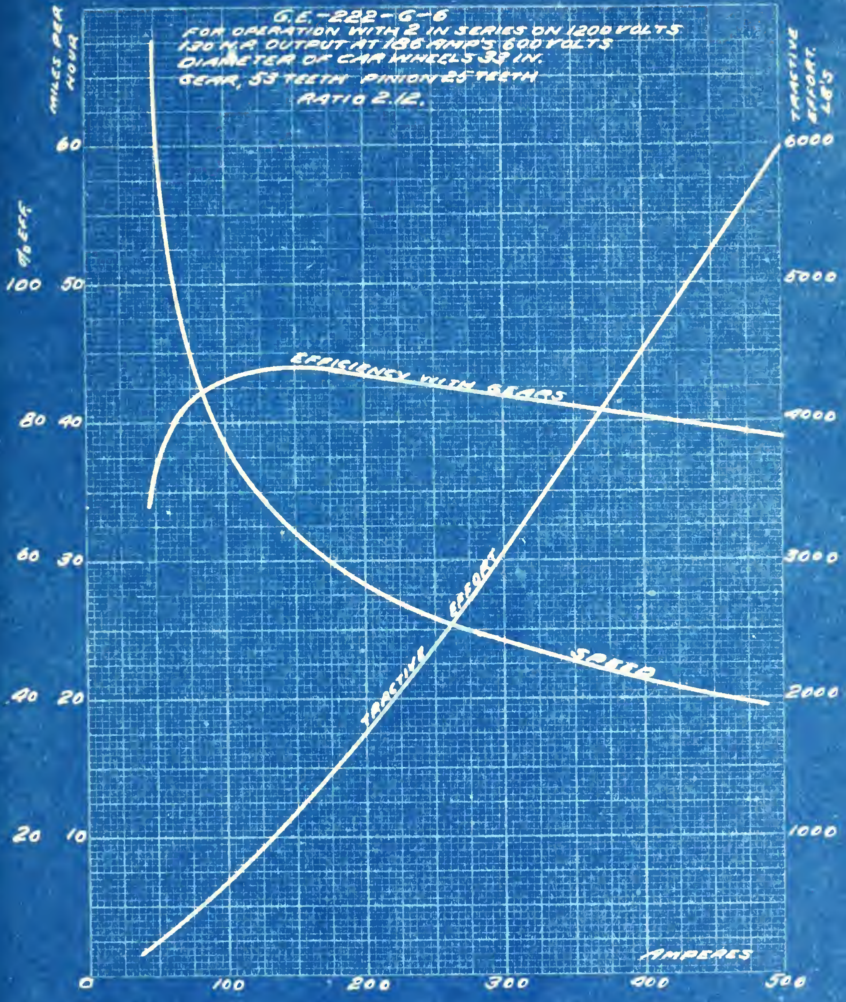

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Figure No. 23

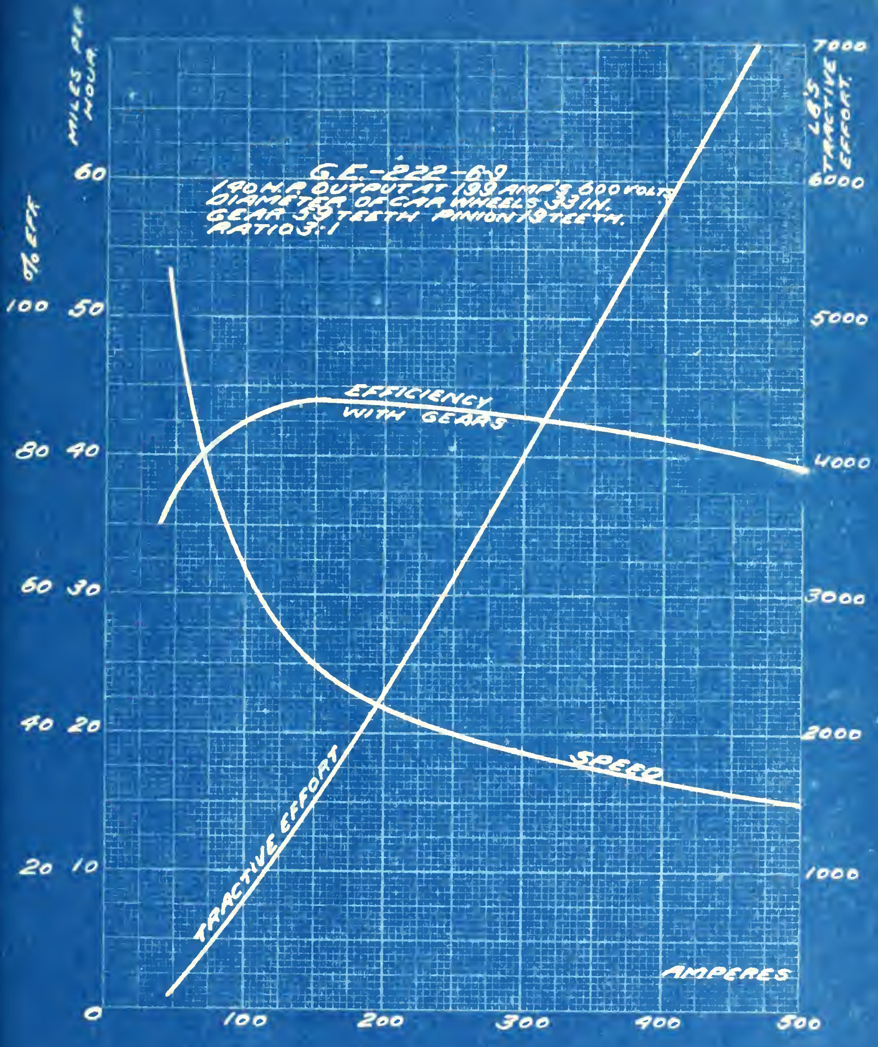

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Figure No. 24

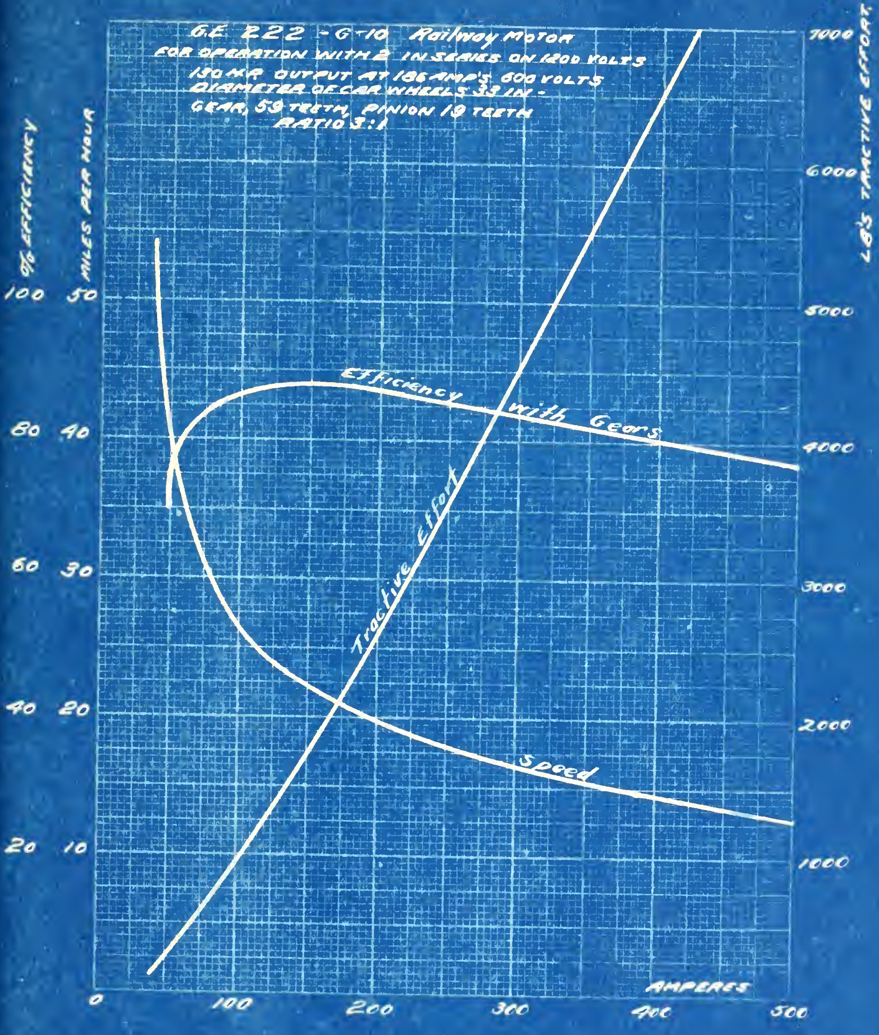

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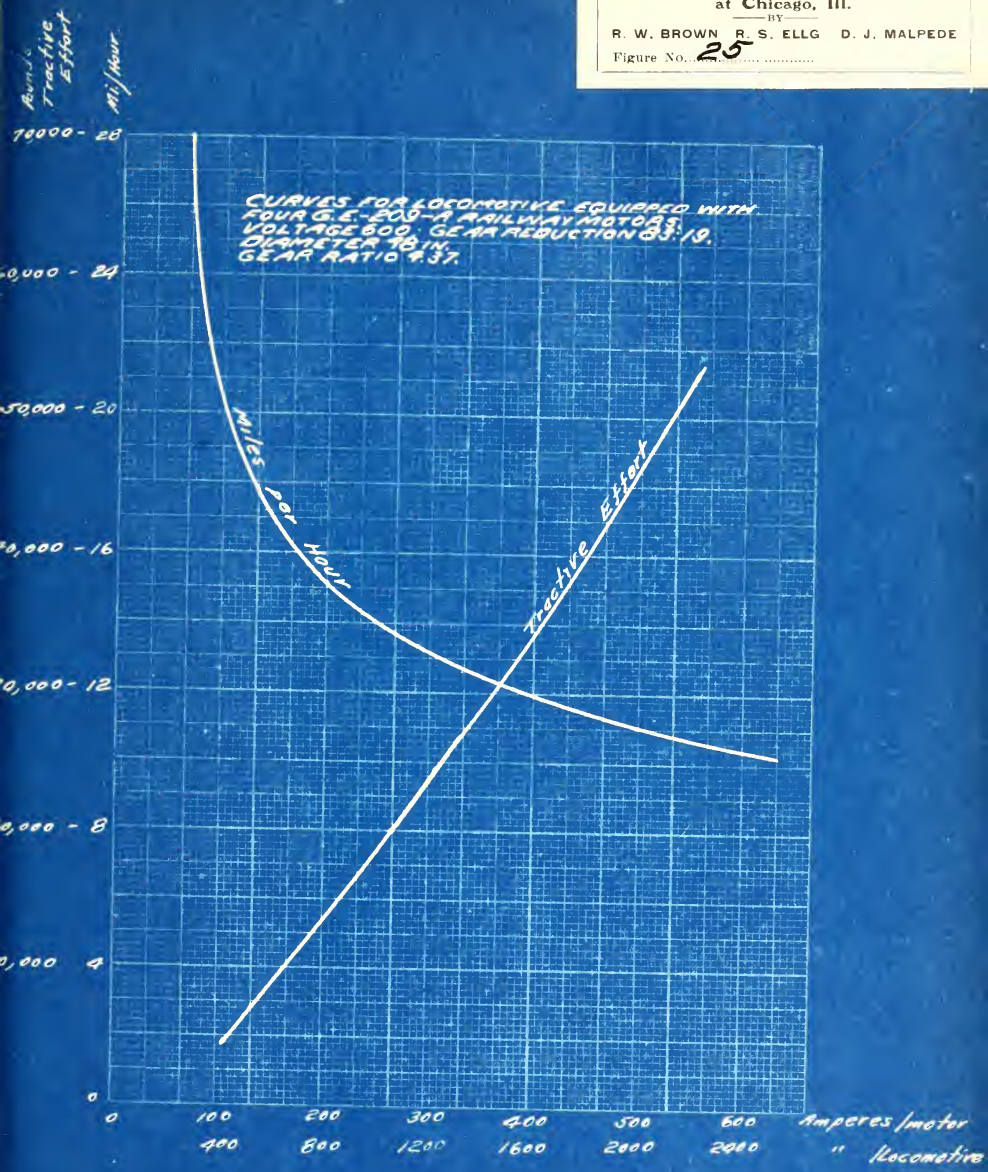
Figure No. 25



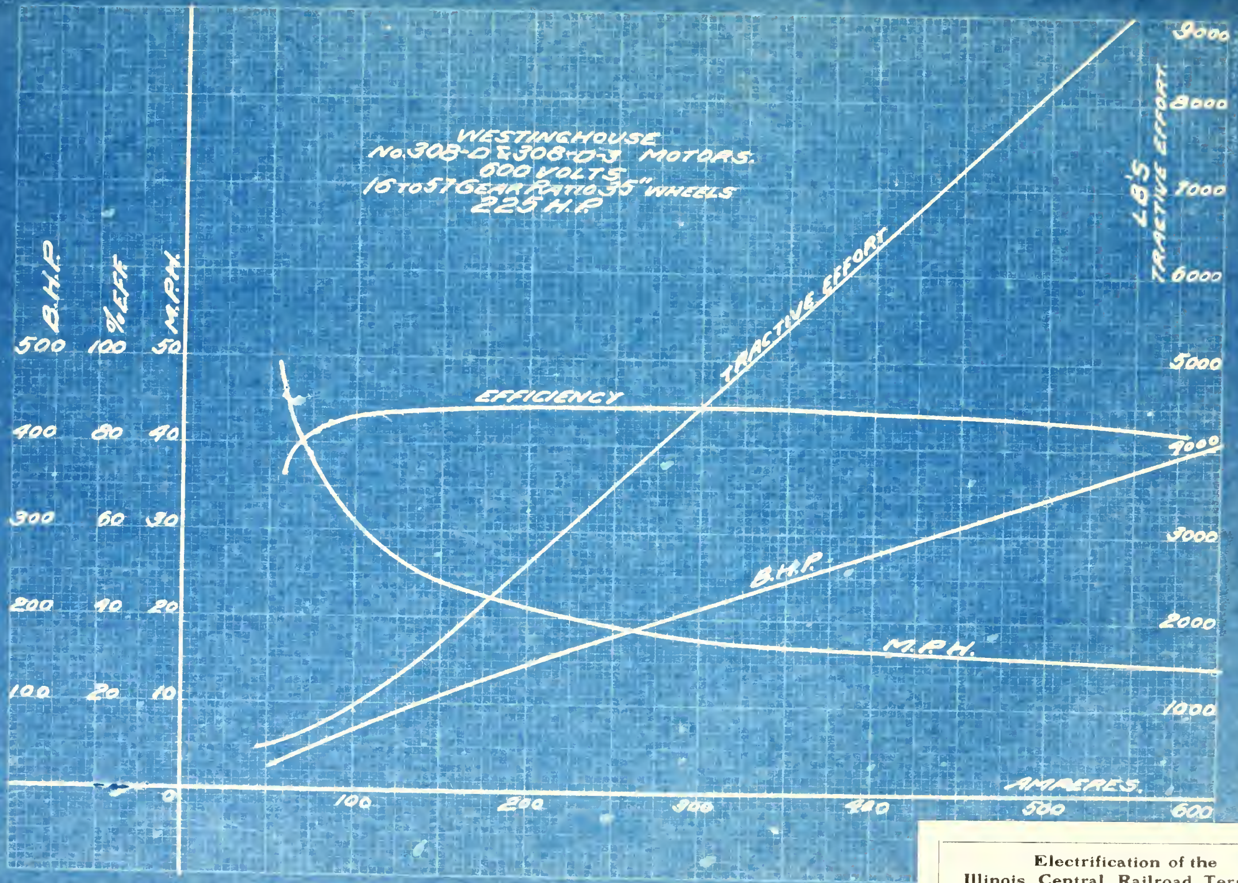


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Figure No. 26

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Figure No. 27

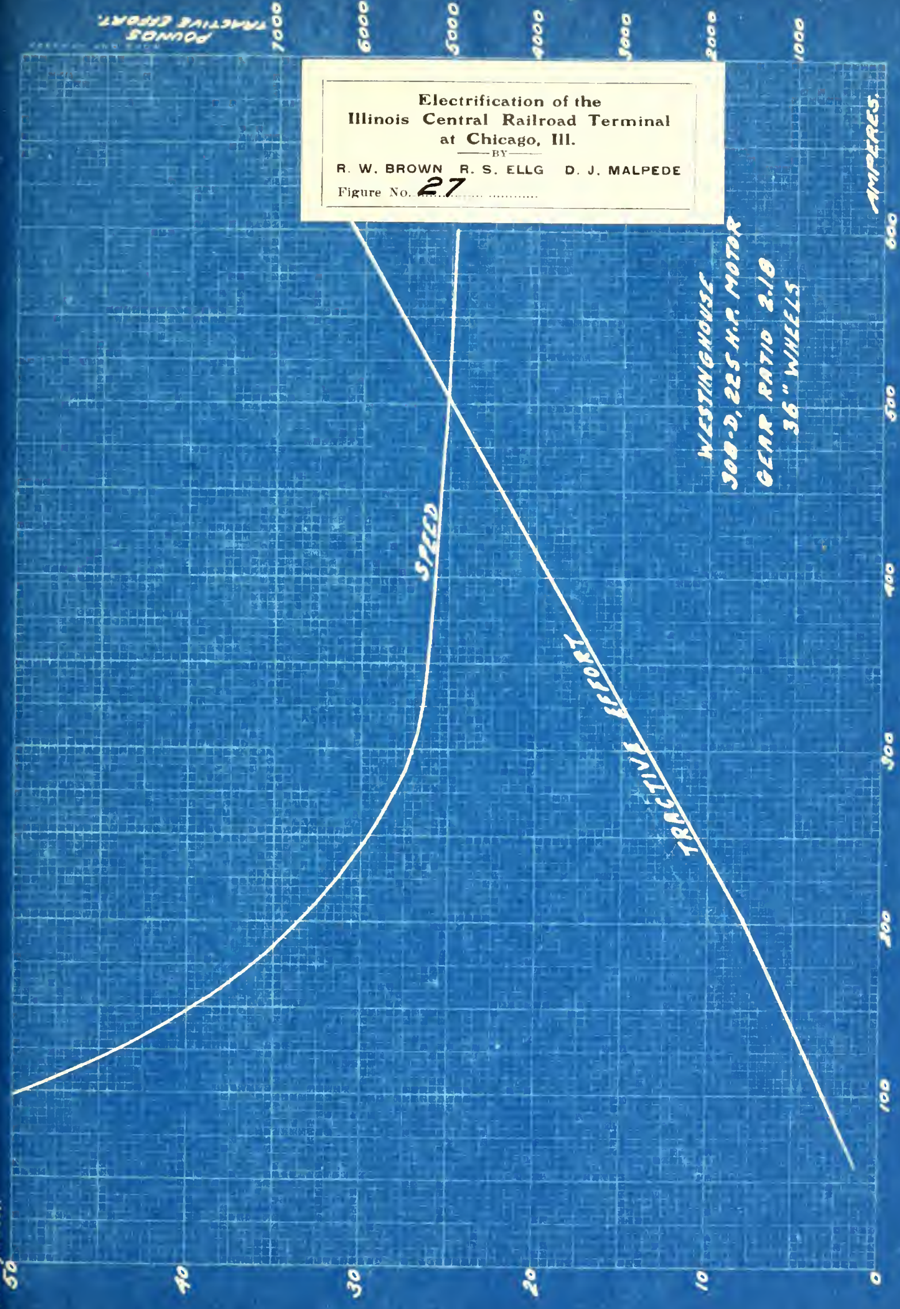

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Figure No. 28

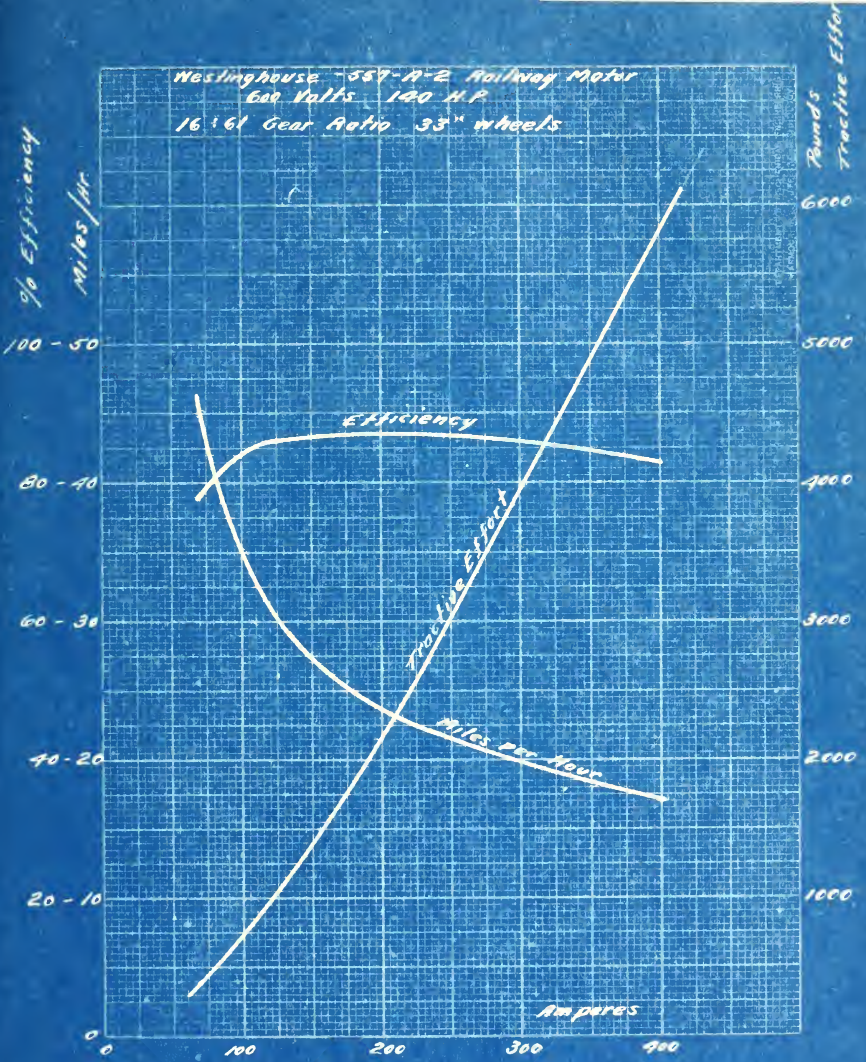

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Figure No. 29

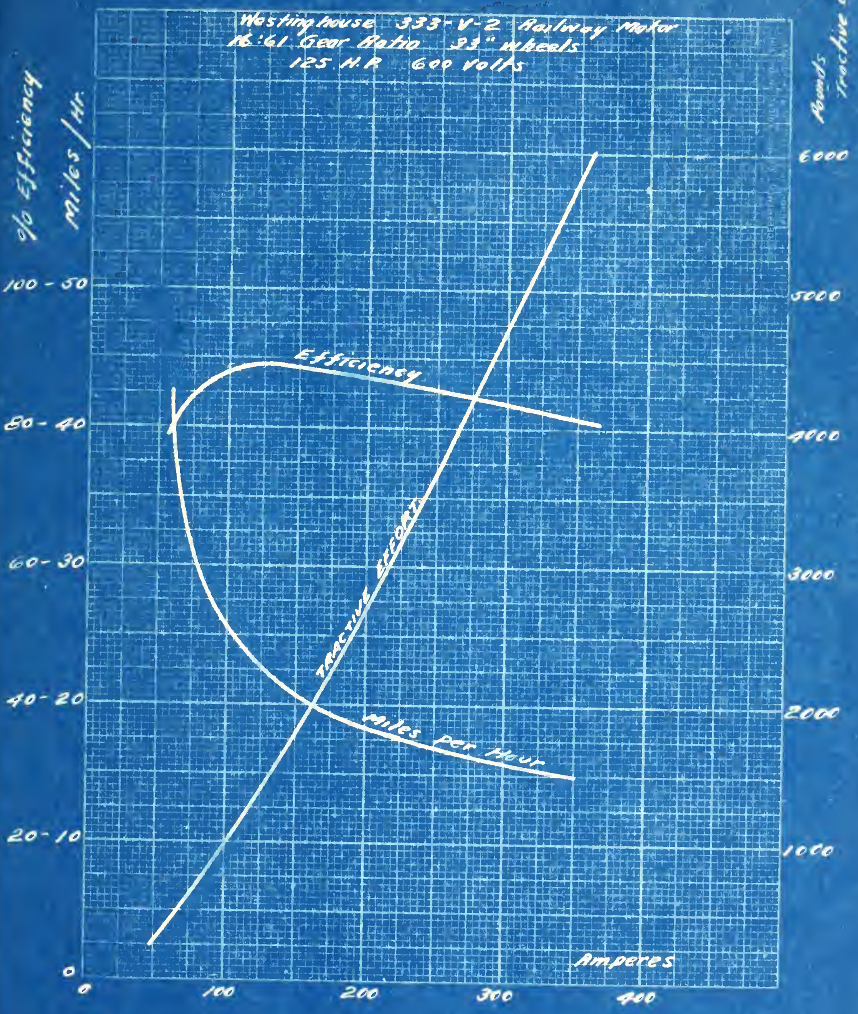

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Figure No. 30

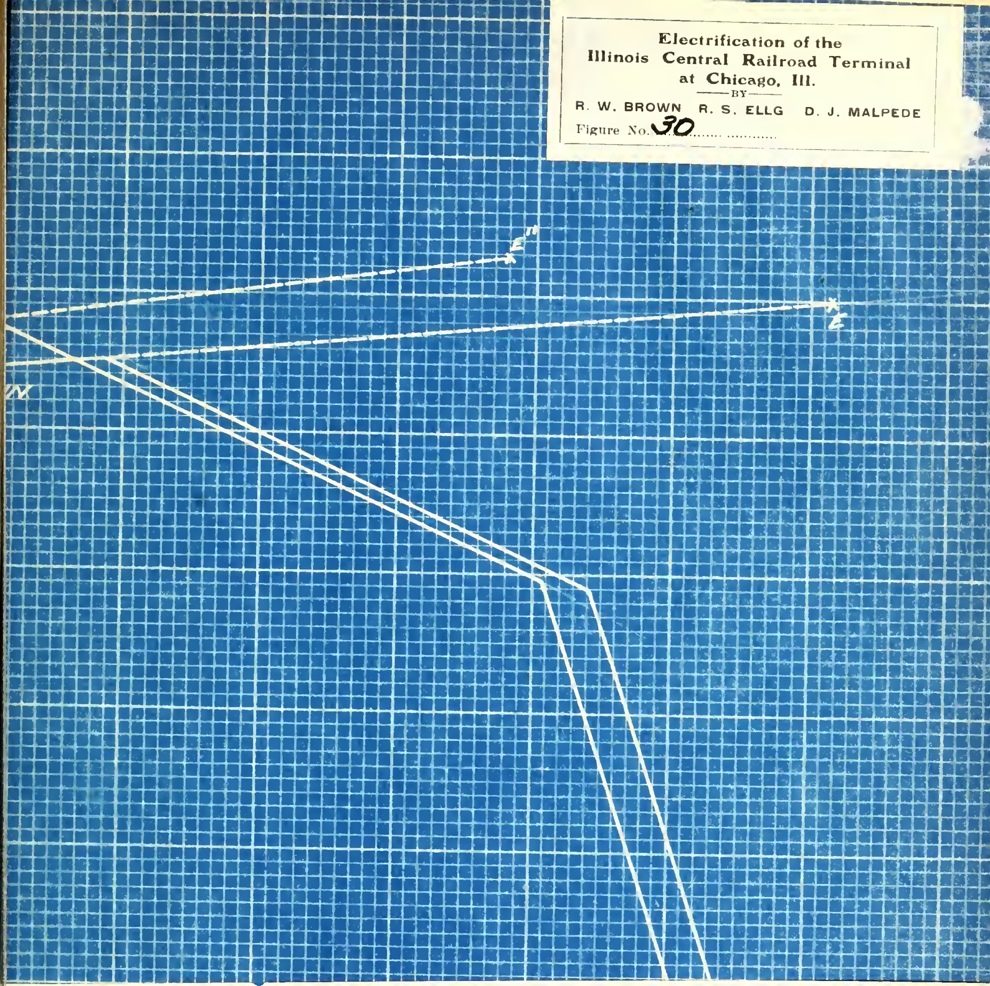

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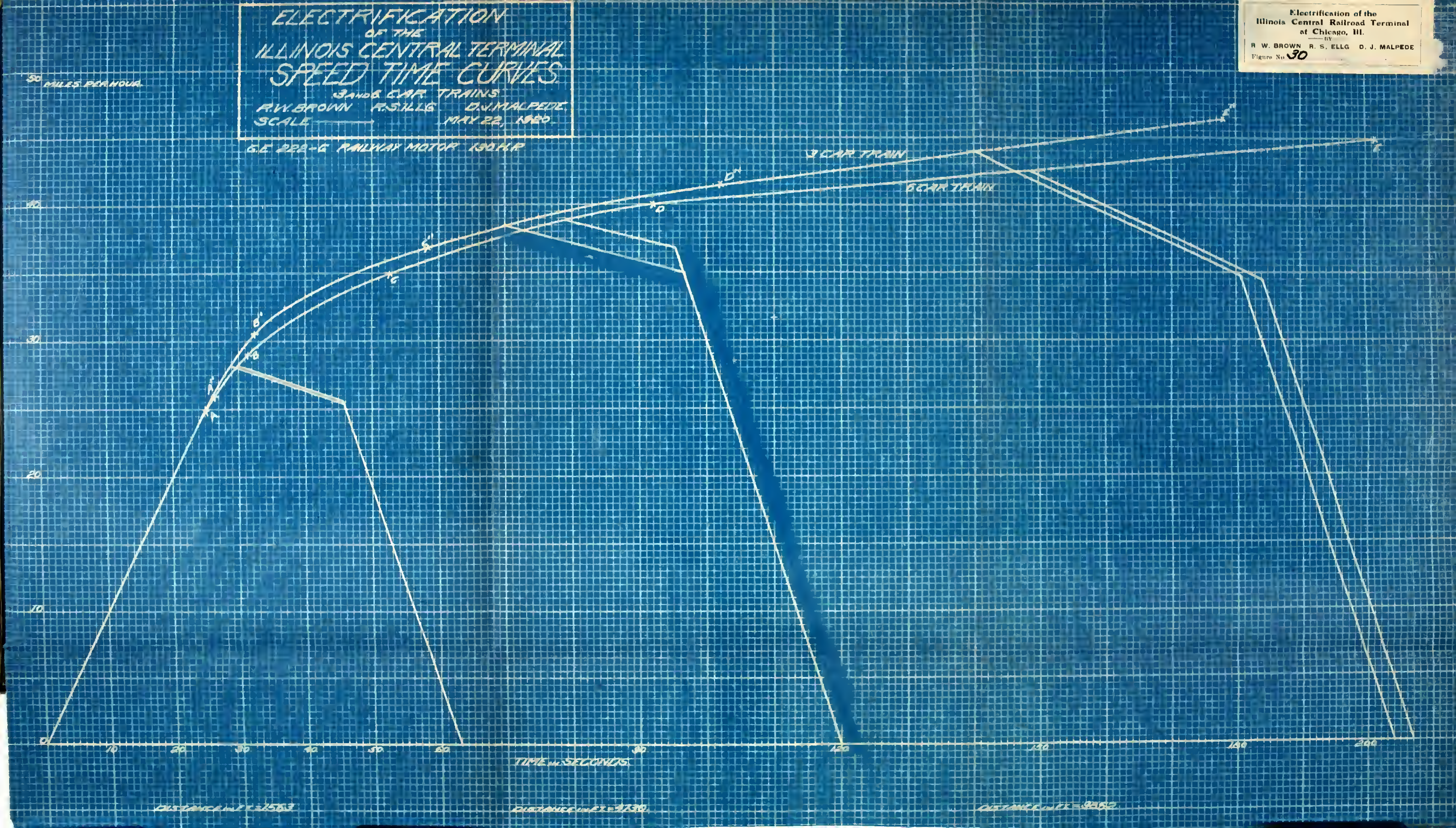
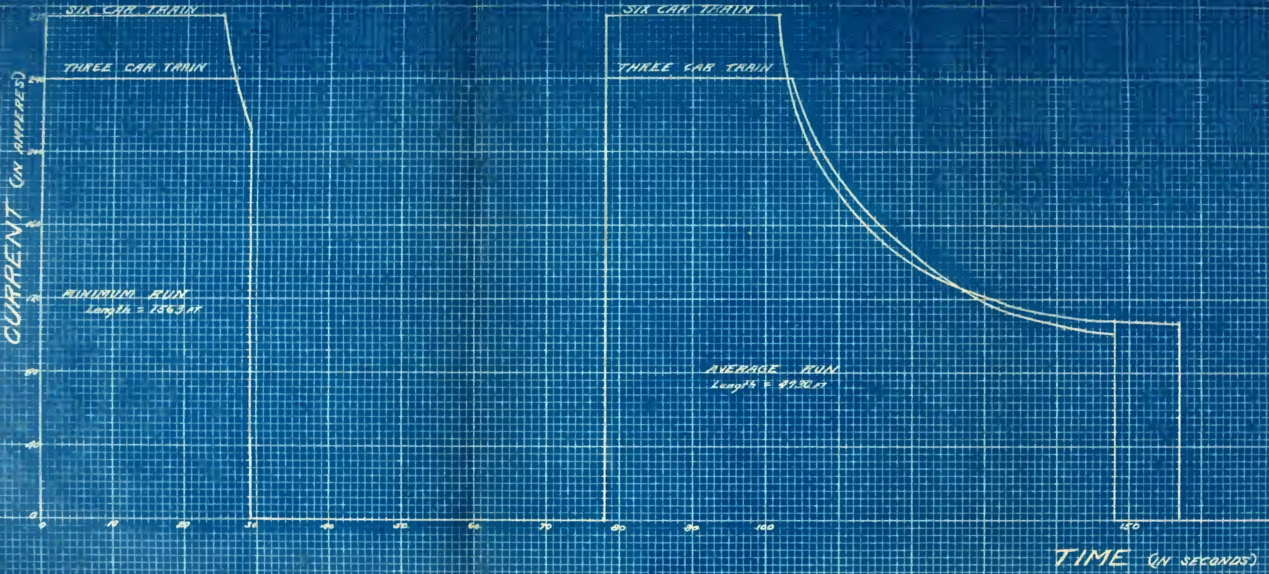
Figure No. 30




SIX CAR TRAIN
THREE CAR TRAIN
SIX CAR TRAIN
THREE CAR TRAIN
MINIMUM RUN
Length = 1563 FT
AVERAGE RUN
Length = 4730 FT
CURRENT (IN AMPERES)
160
120
80
40
0
0
10
20
30
40
50
60
70
80
90
100
150
TIME (IN SECONDS)

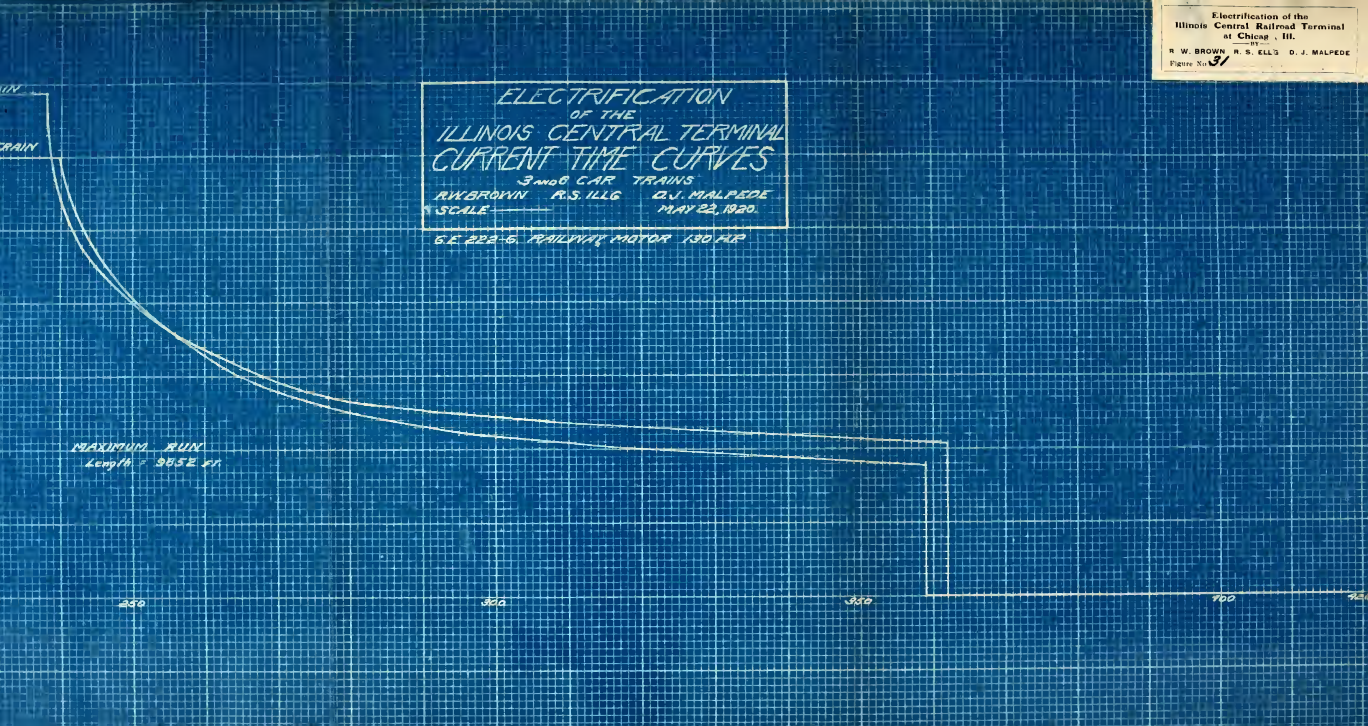


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Figure No 31

Electrification of the
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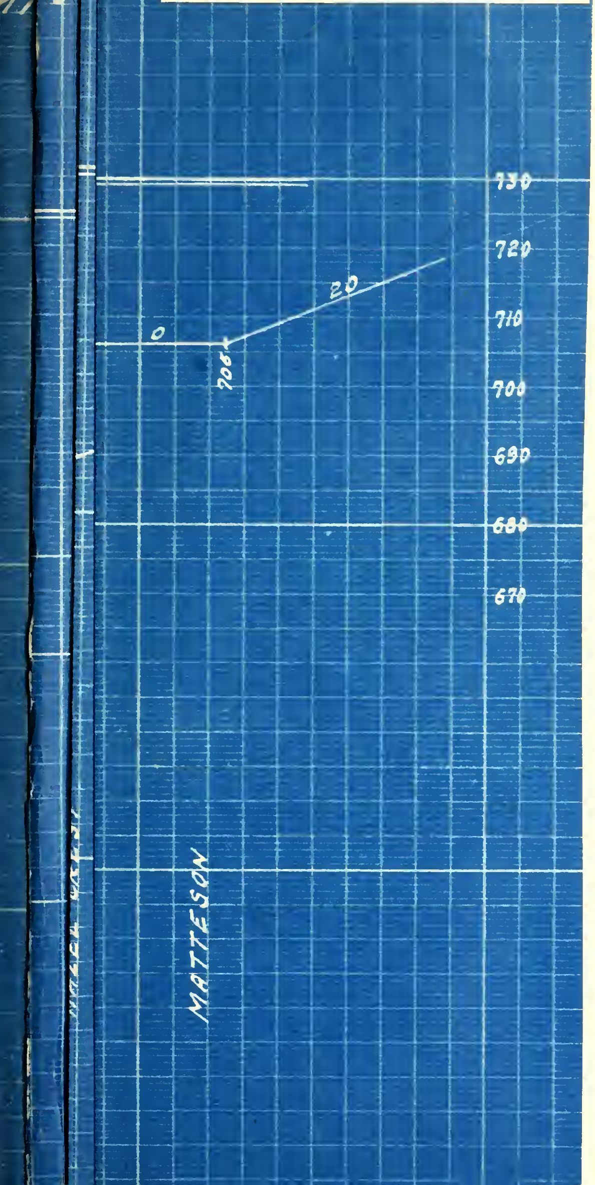
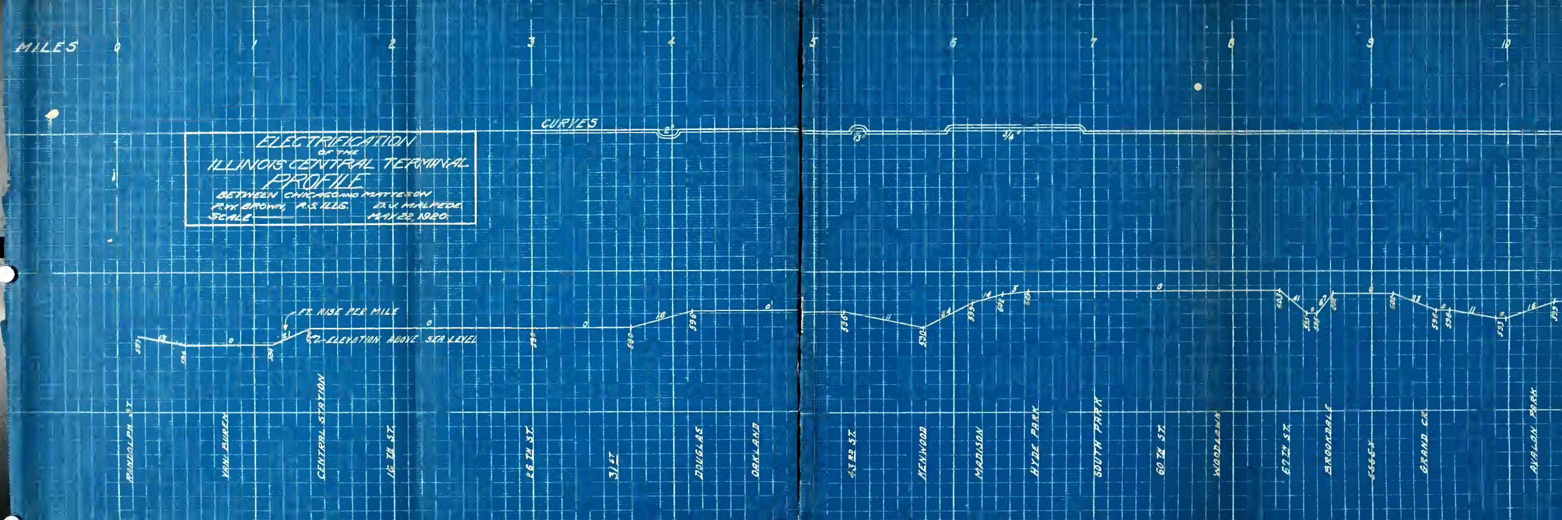
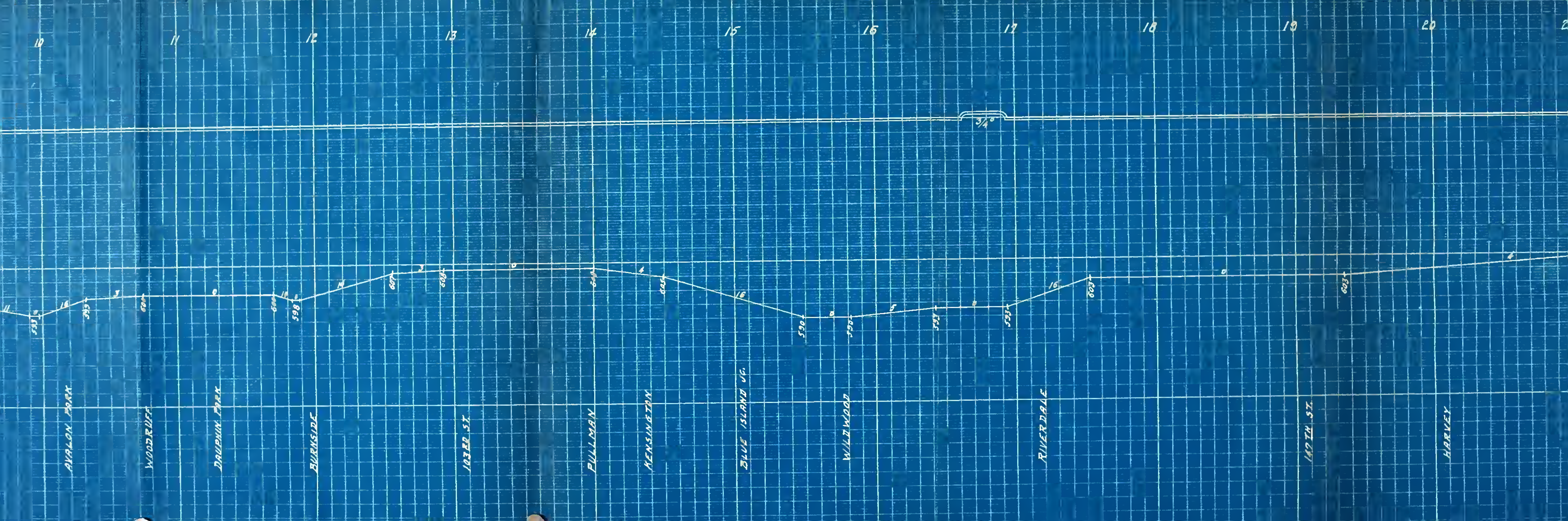
Figure No. 1

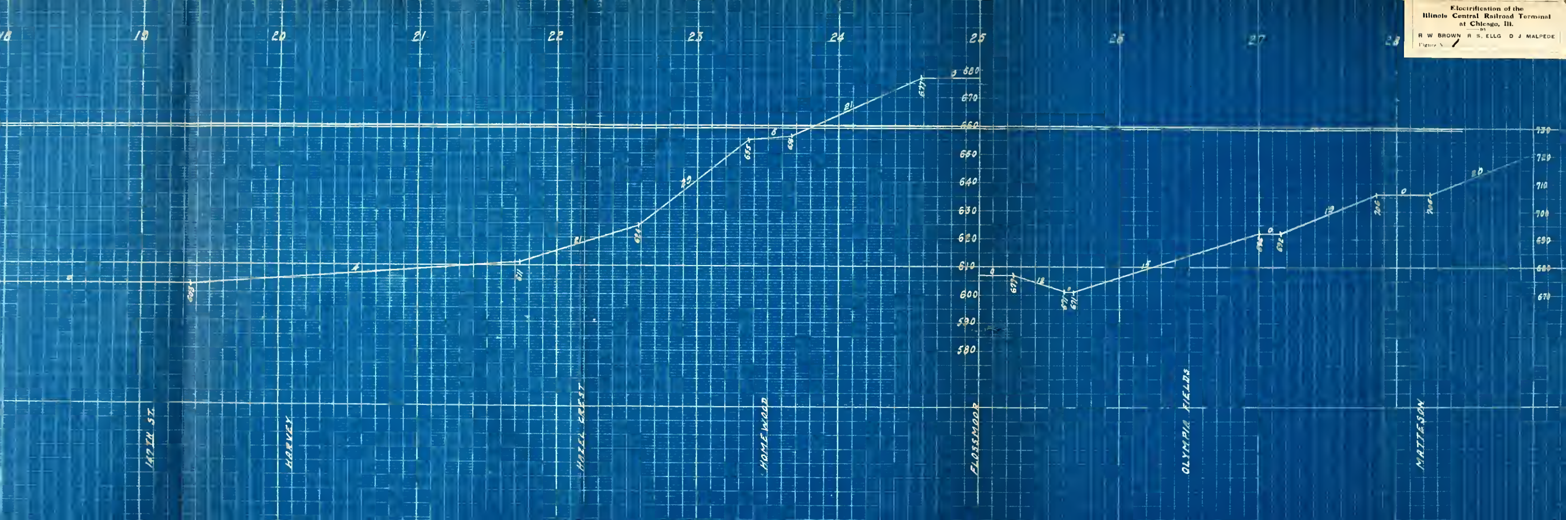




ELECTRIFICATION
OF THE
ILLINOIS CENTRAL TERMINAL
PROFILE
BETWEEN CHICAGO AND MATTESON
A.W. BROWN, A.S.I.L.C.   D.J. MALPEDE.
SCALE ———   MAY 22, 1920.


3/4°
AVALON PARK
WOODRUFF
DAUPHIN PARK
BURNSIDE
103RD ST.
PULLMAN
KENSINGTON
BLUE ISLAND JC.
WILDWOOD
RIVERDALE
147TH ST.
HARVEY

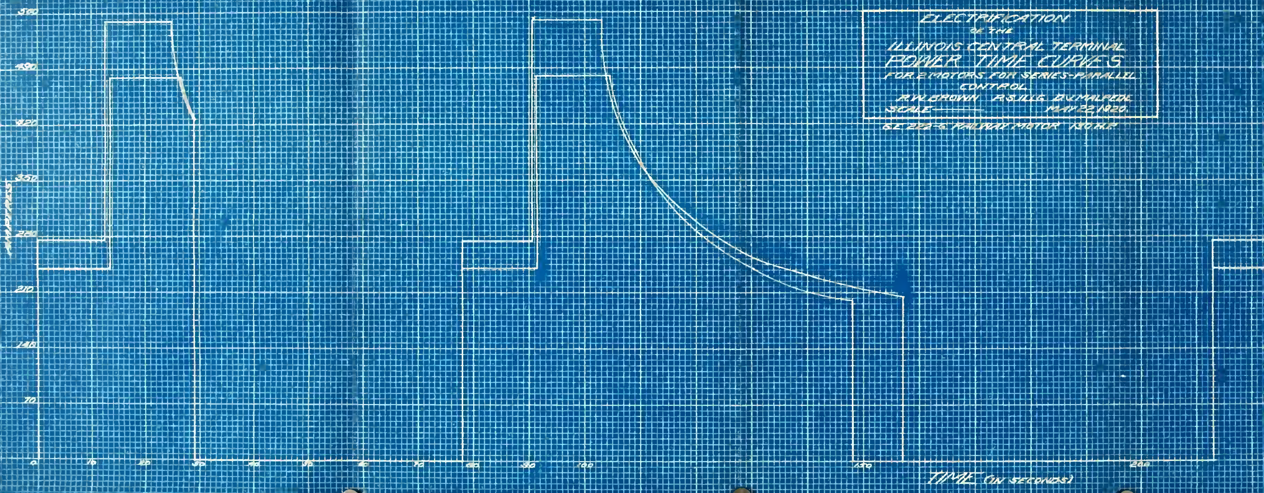
Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
by
R W BROWN R S. ELLIS D J MALPEDE
Figure No. 1



Brown-Sequi Malfeds —
Thesis -

Electrification of the
linois Central Railroad Terminal
at Chicago, Ill.
BY
W. BROWN R. S. ELLG D. J. MALPEDE

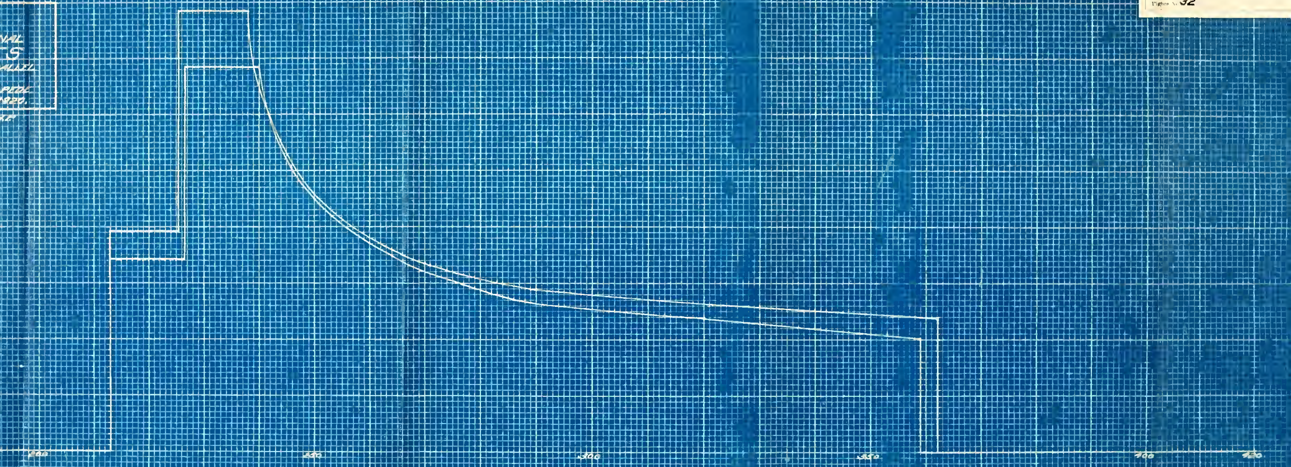
ure No. 32

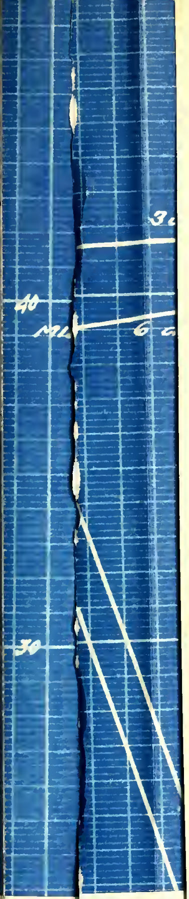


ELECTRIFICATION
OF THE
ILLINOIS CENTRAL TERMINAL
POWER TIME CURVES
FOR 2 MOTORS FOR SERIES-PARALLEL
CONTROL
R.W. BROWN R.S. ILLG D.V. MALPEDE
SCALE———— MAY 22, 1920.

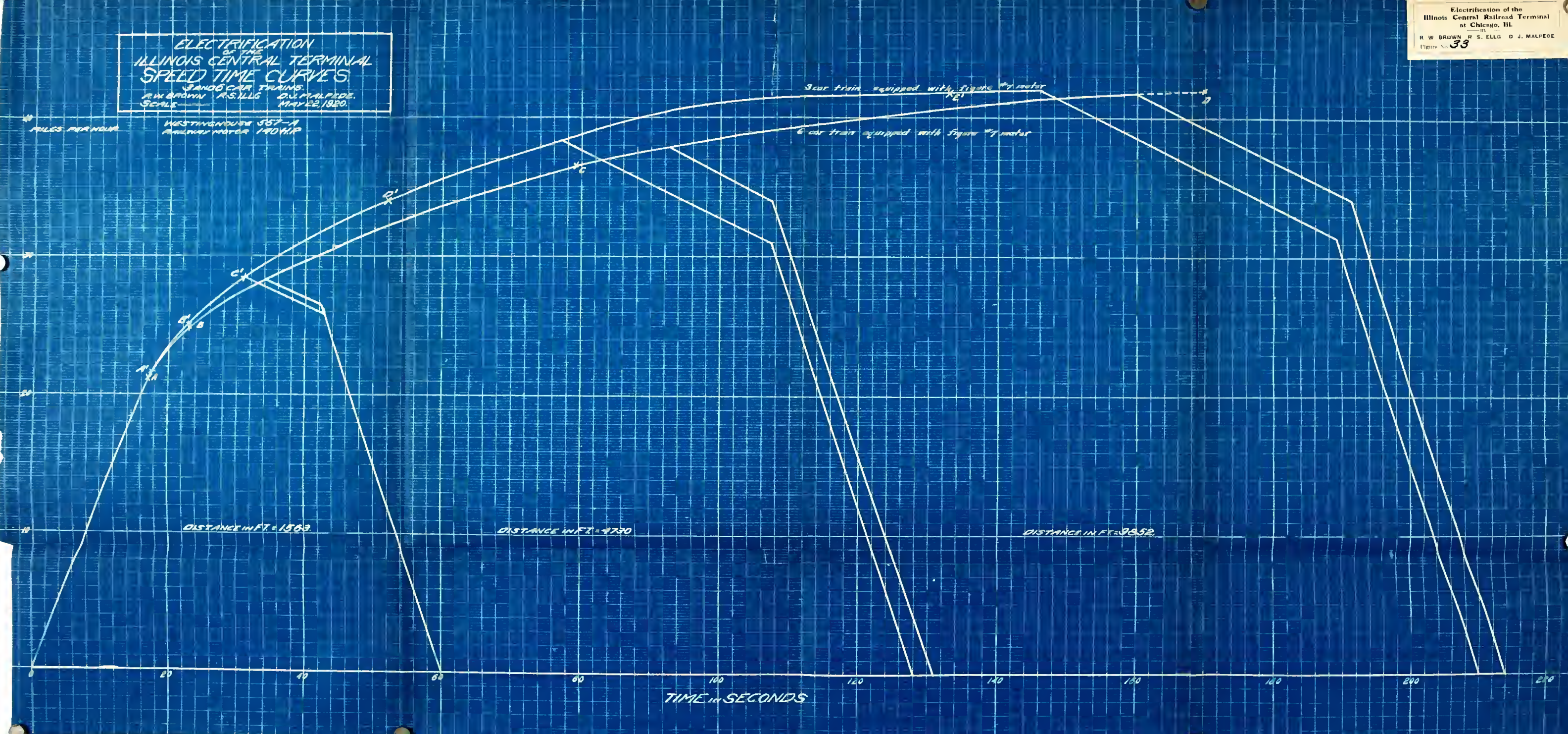
G.E. 222-G RAILWAY MOTOR 130 H.P.

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—— BY ——
R W BROWN R S ELLG D J MALPEDE
Figure No. 32

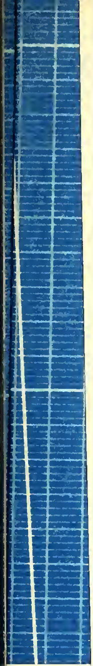


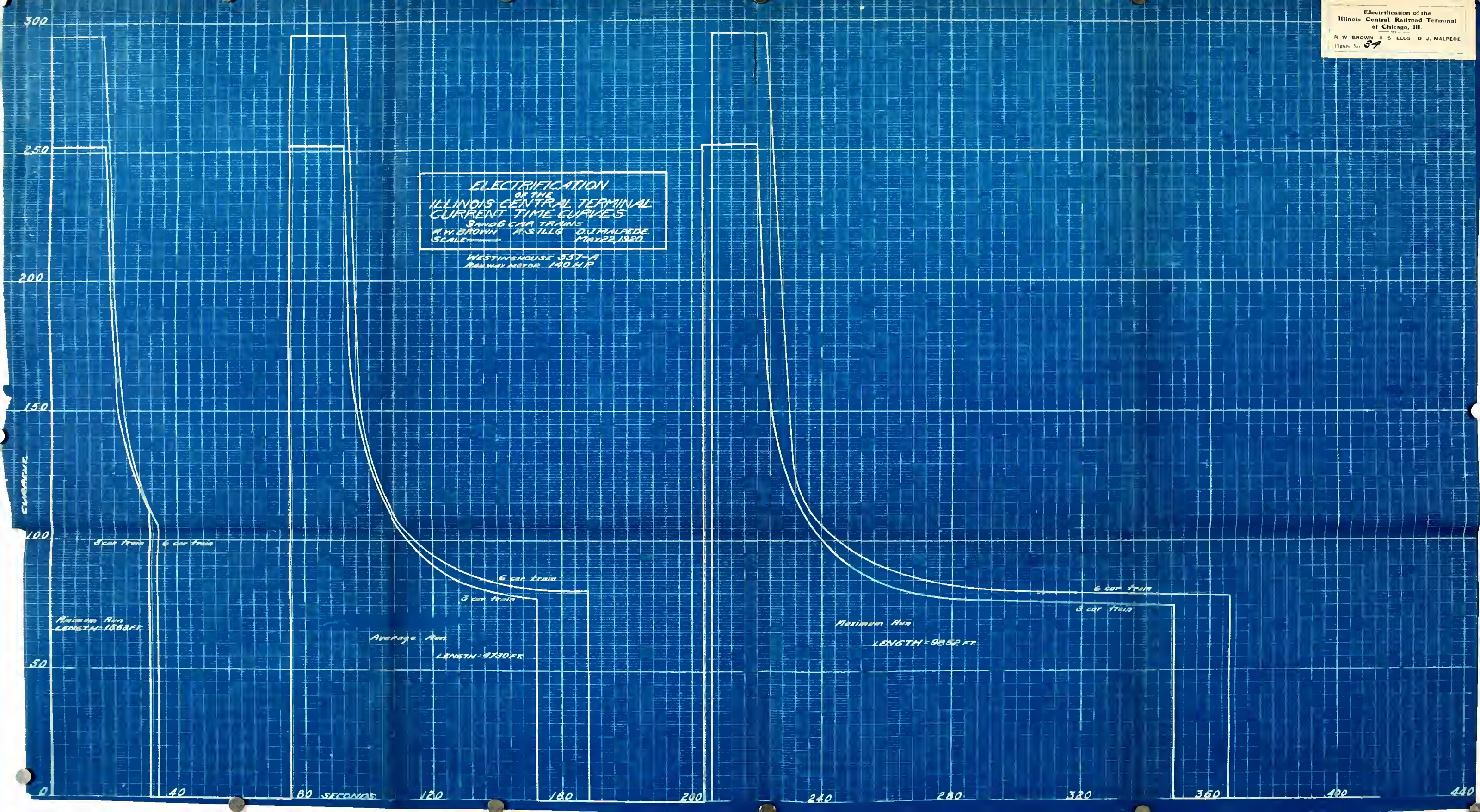

3
40
ML
6
30

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
BY
R. W. BROWN R. S. ELLG D. J. MALPEDE
Figure No. 33



ELECTRIFICATION
OF THE
ILLINOIS CENTRAL TERMINAL
SPEED TIME CURVES.
3 AND 6 CAR TRAINS.
R. W. BROWN R. S. ILLG D. J. MALPEDE.
SCALE——— MAY 22, 1920.





Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
BY
R W BROWN R S ELLG D J. MALPEDE
Figure No 34

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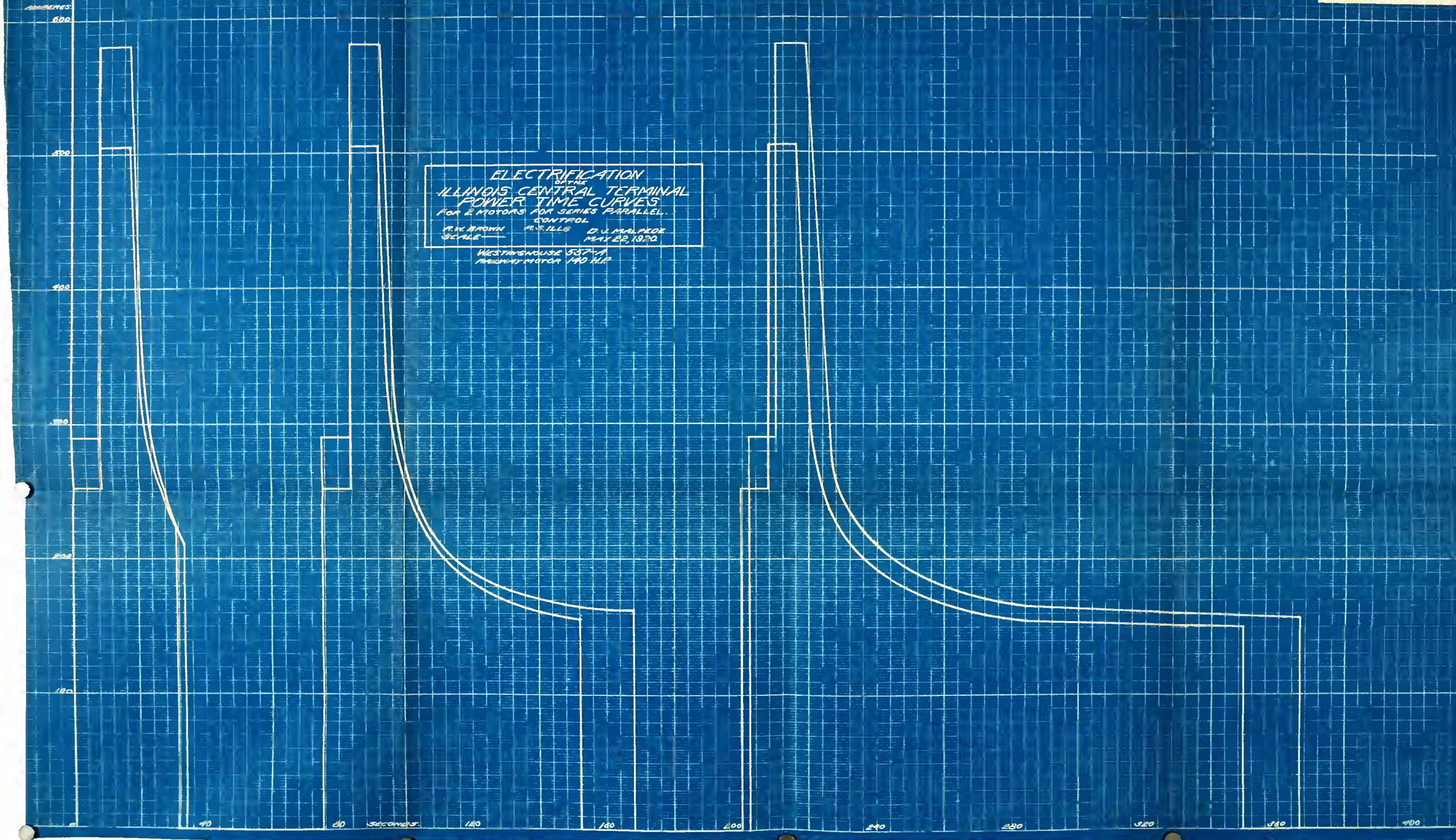
Electrification of the
Illinois Central Railroad Termina
at Chicago, Ill.
—BY—
R W BROWN R S. ELLG D J MALPE
Figure No 35



ELECTRIFICATION
OF THE
ILLINOIS CENTRAL TERMINAL
POWER TIME CURVES
FOR 2 MOTORS FOR SERIES PARALLEL.
CONTROL
R.W. BROWN R.S. ILLG D.J. MALPEDE
SCALE—— MAY 22, 1920.

WESTINGHOUSE 557-A
RAILWAY MOTOR 140 H.P.

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
BY
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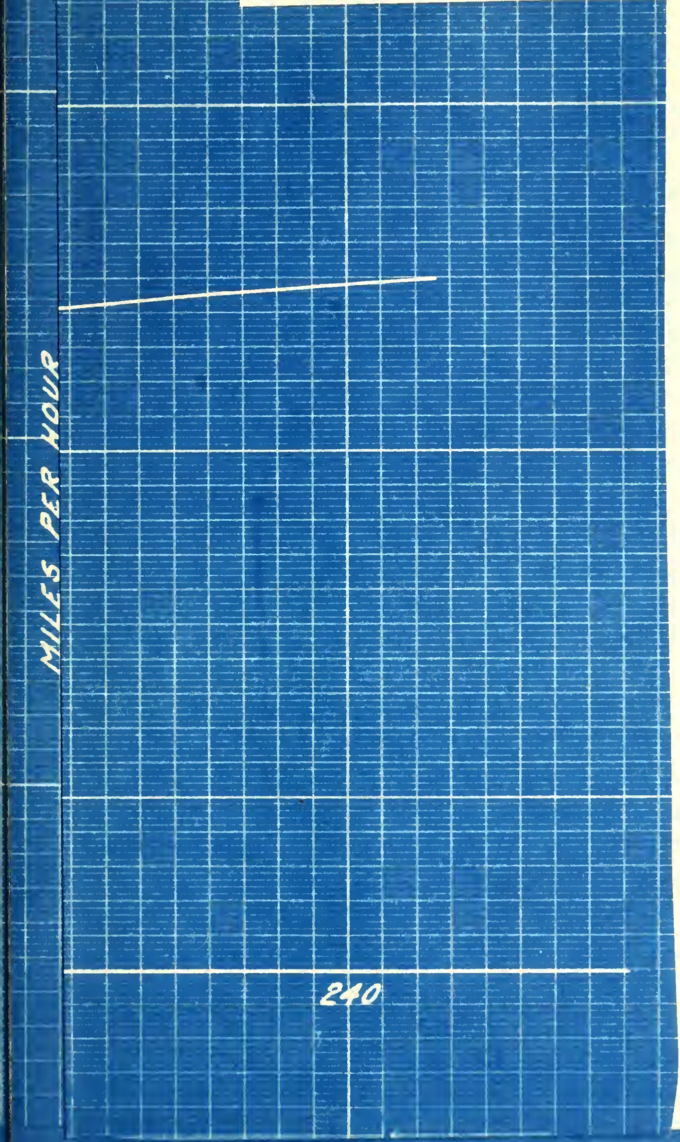
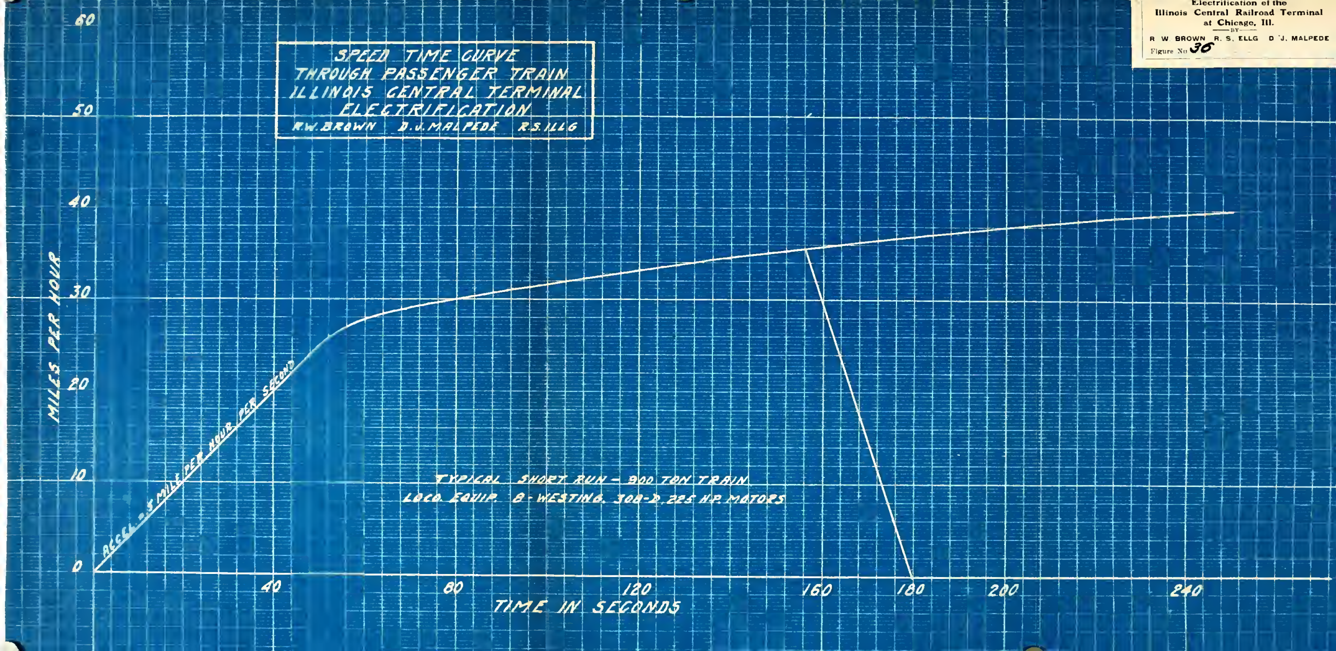
Figure No. 36



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—BY—
R. W. BROWN R. S. ELLG D. J. MALPEDE
Figure No 36



SPEED TIME CURVE
THROUGH PASSENGER TRAIN
ILLINOIS CENTRAL TERMINAL
ELECTRIFICATION
R.W. BROWN D.J. MALPEDE R.S. ILLG

TYPICAL SHORT RUN - 900 TON TRAIN
LOCO. EQUIP. 8 - WESTING. 300-D. 225 H.P. MOTORS

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
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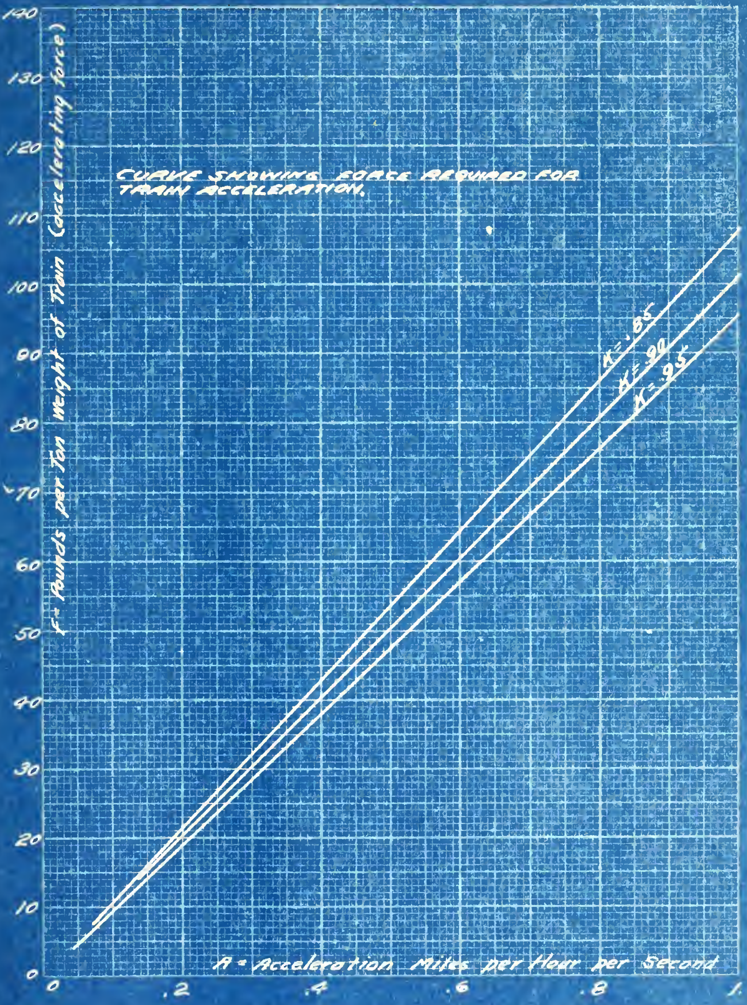
R. W. BROWN R. S. ELLG D. J. MALPEDE

Figure No. 38



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—BY—
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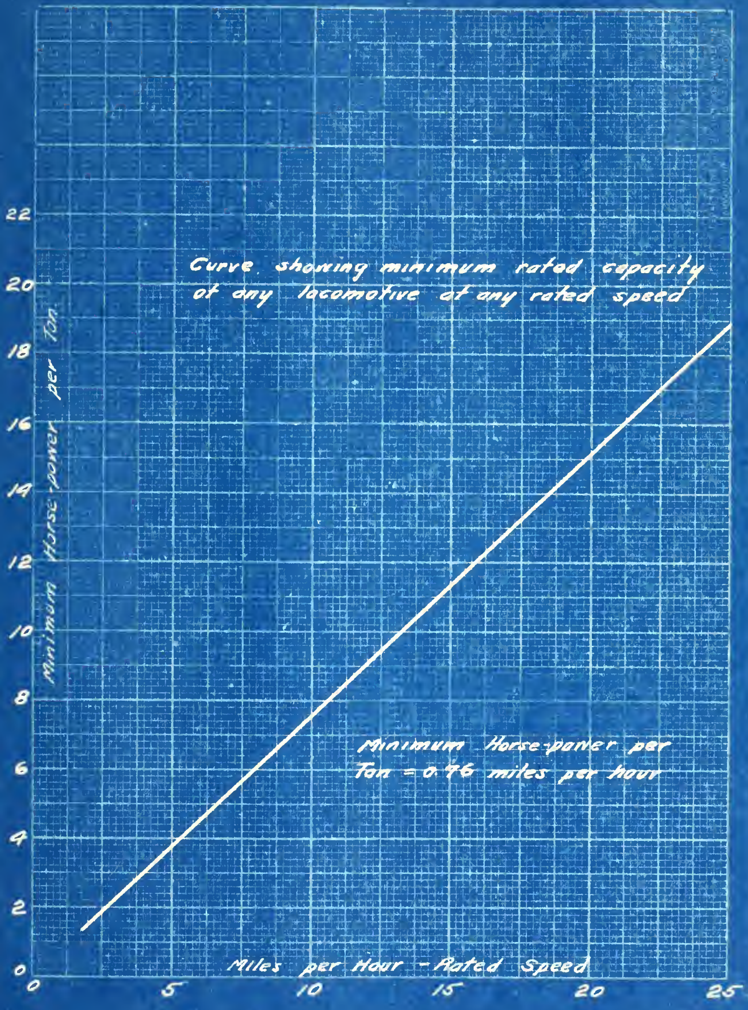
Figure No. 39



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
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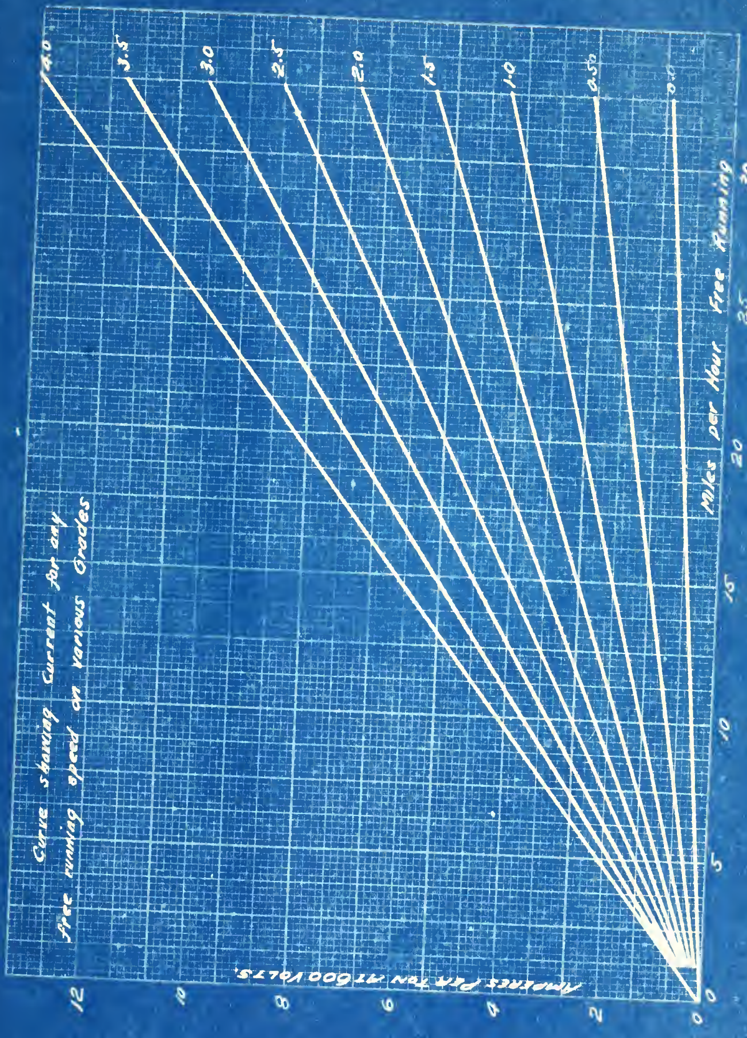
41



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
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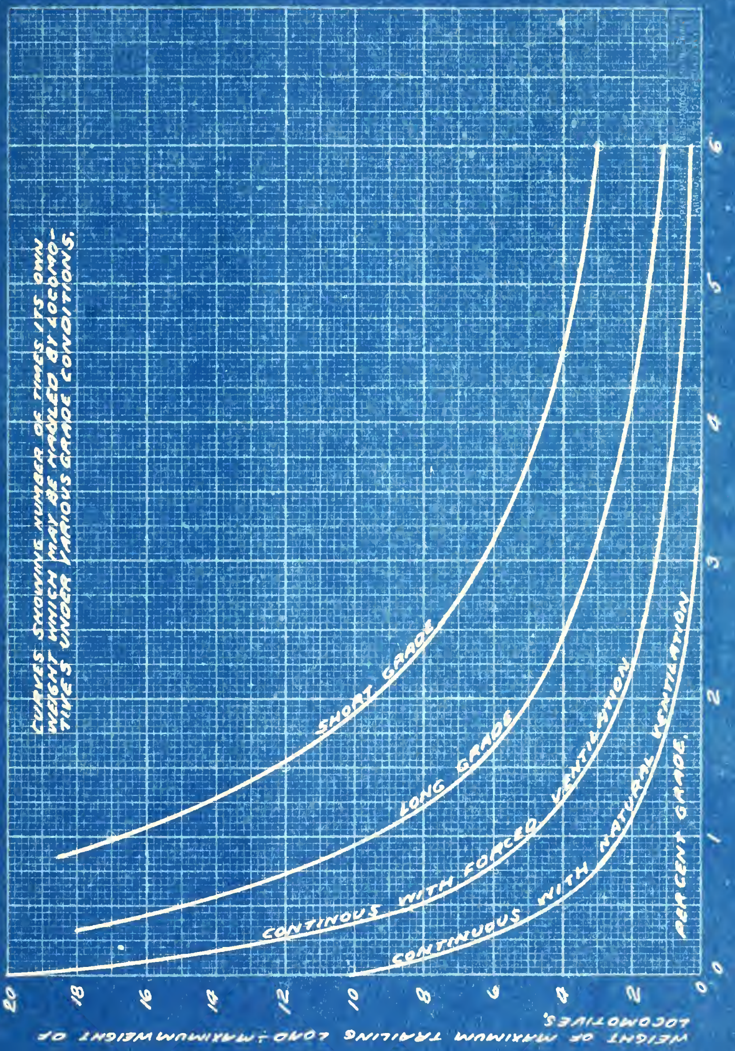
Figure No. 40.

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—BY—
R. W. BROWN   R. S. ELLG   D. J. MALPEDE
Figure No. 41



Electrification of the Illinois Central Railroad Terminal at Chicago, Ill.

—BY—

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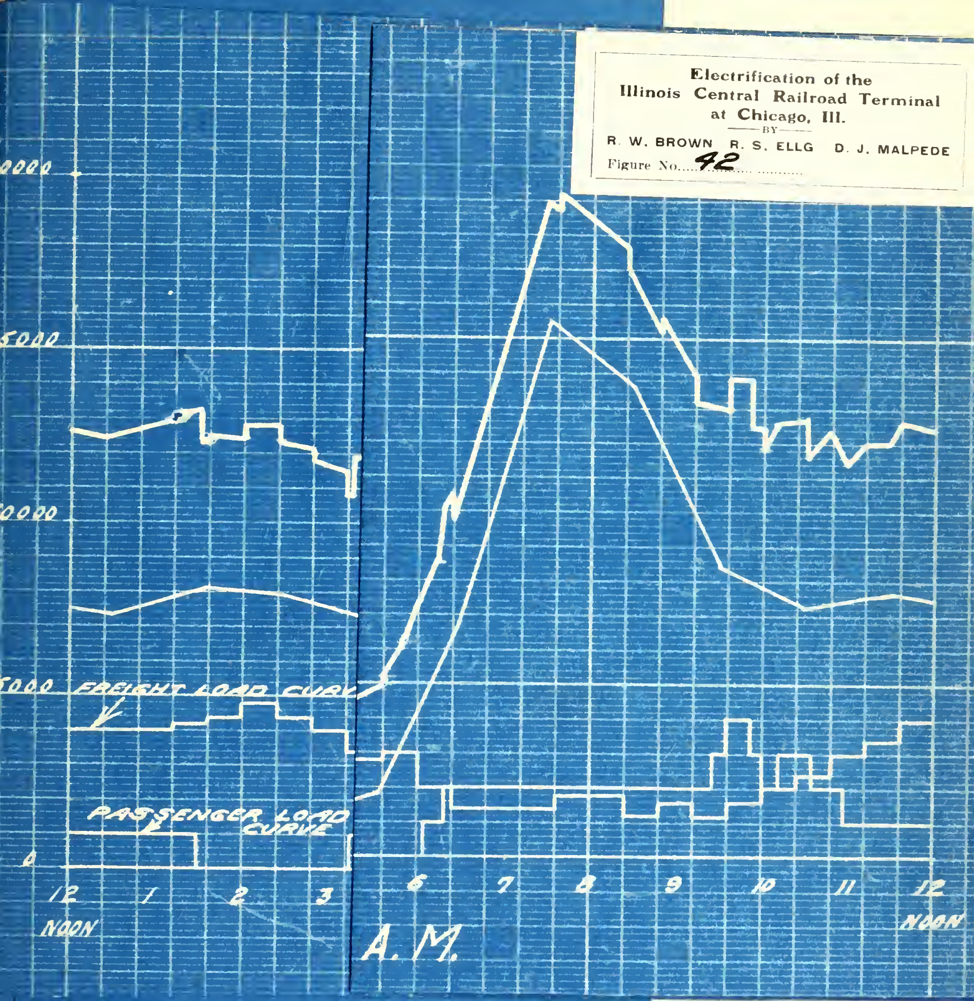
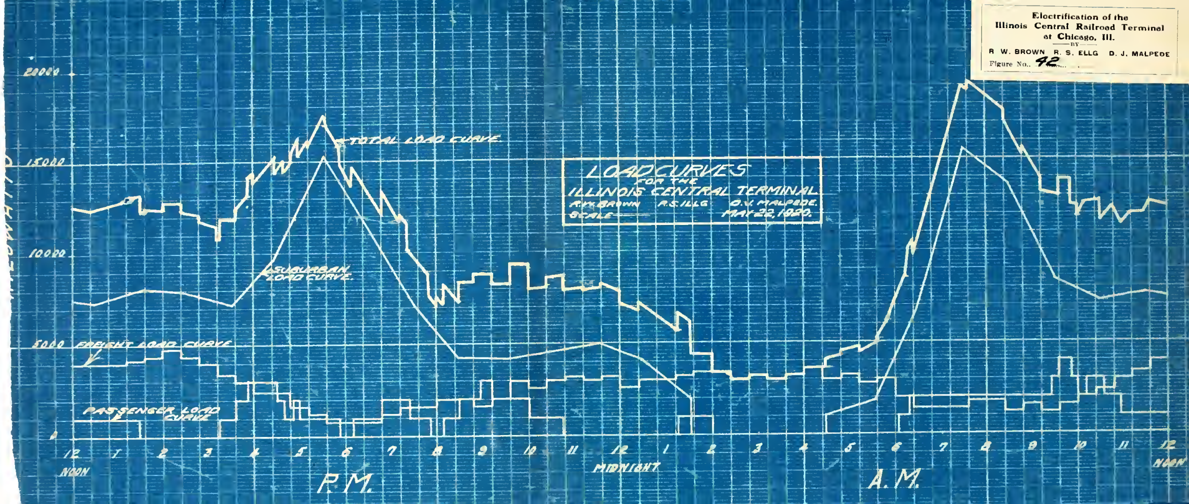
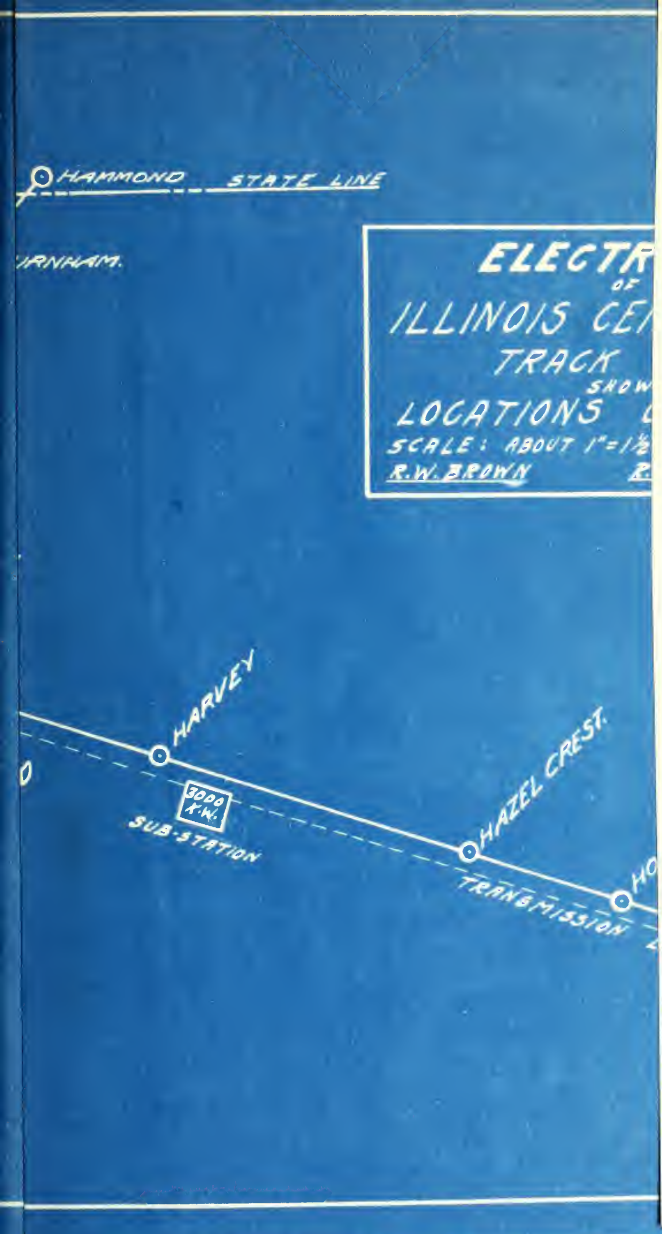
Figure No. 42



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
—BY—
R. W. BROWN R. S. ELLG D. J. MALPEDE
Figure No. 42

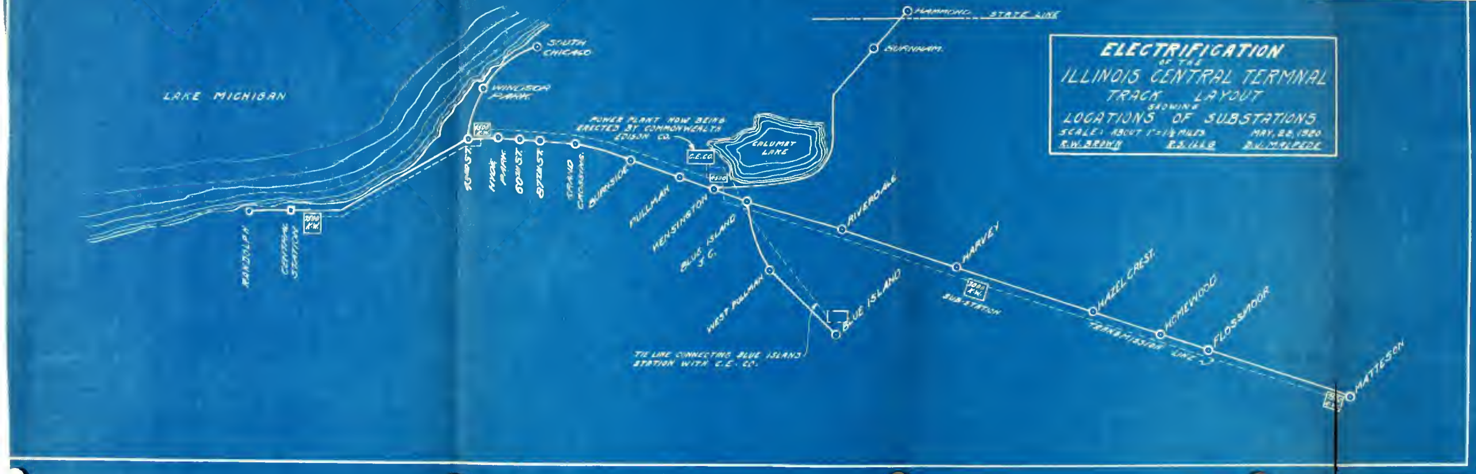



HAMMOND
STATE LINE
IRNHAM.
ELECTR
OF
ILLINOIS CE
TRACK
SHOW
LOCATIONS
SCALE: ABOUT 1"=1½
R.W. BROWN
R.
HARVEY
3000 K.W.
SUB-STATION
HAZEL CREST.
HO
TRANSMISSION
D

Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.

R W BROWN R S ELLG D J. MALPEDE

Figure No. 43



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
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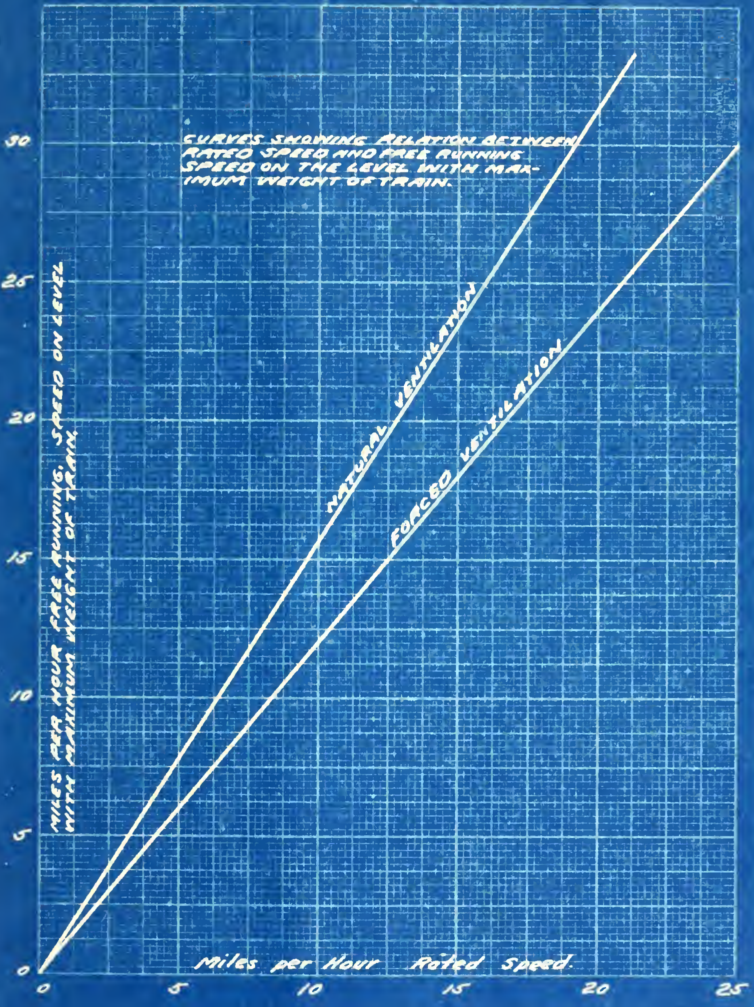
Figure No. 44



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
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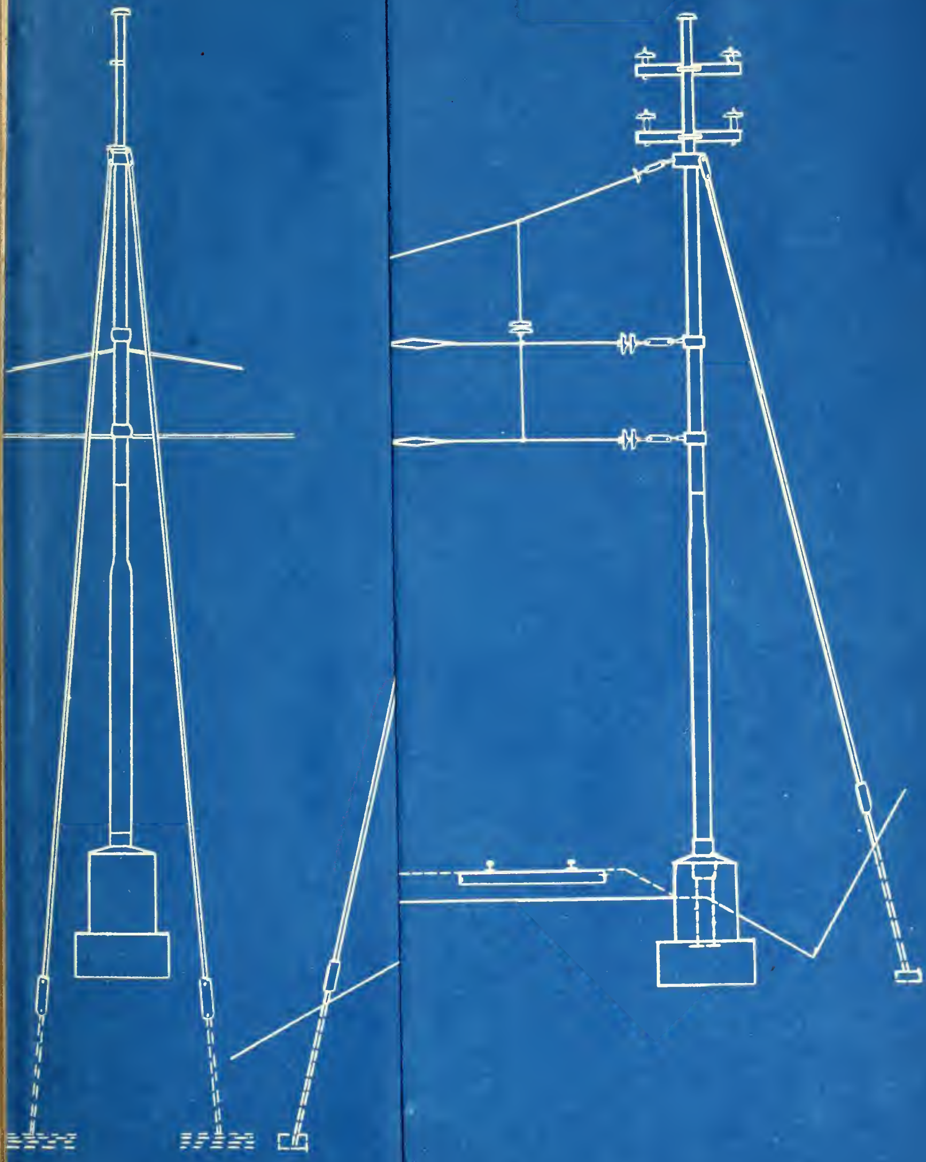
Figure No. 45



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Illinois Central Railroad Terminal
at Chicago, Ill.
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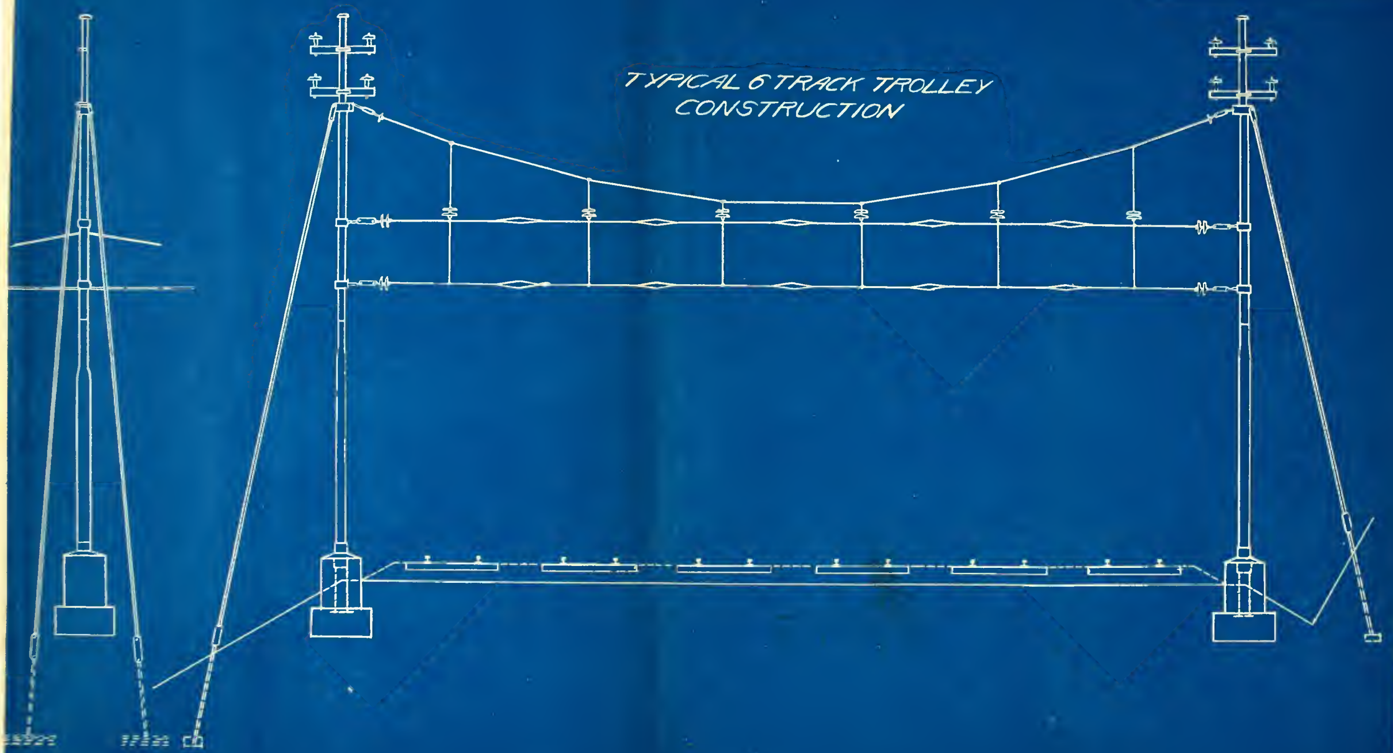
Figure No. 45



Electrification of the
Illinois Central Railroad Terminal
at Chicago, Ill.
BY
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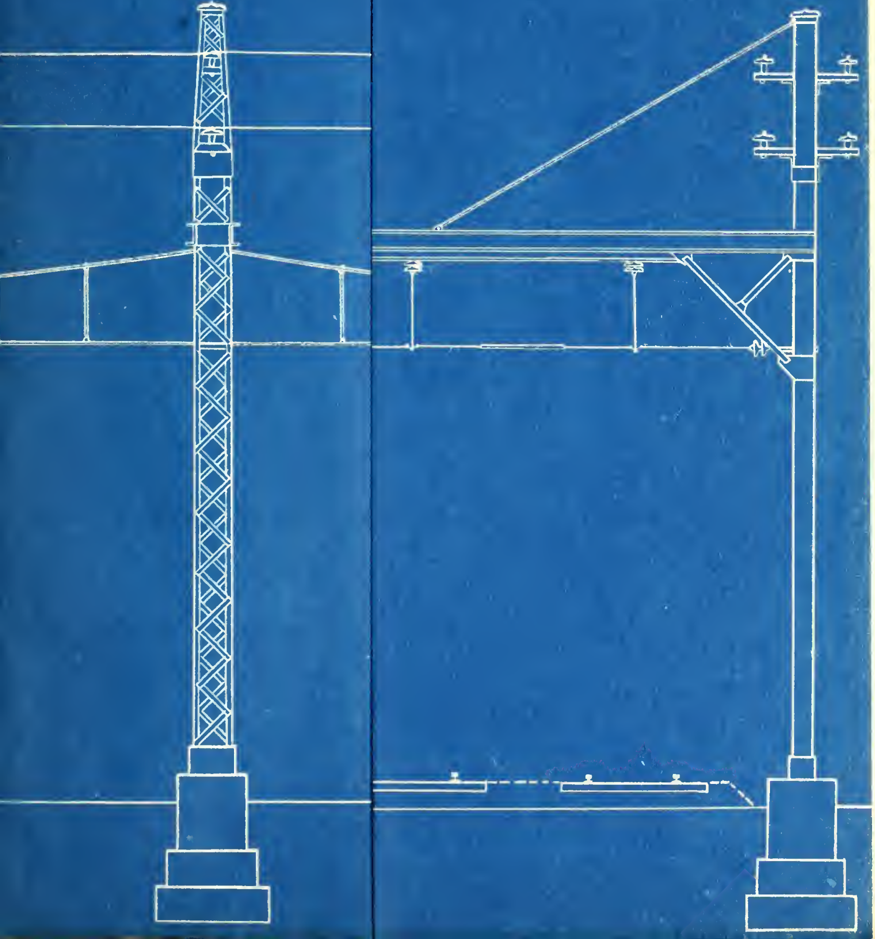
Figure No. 46

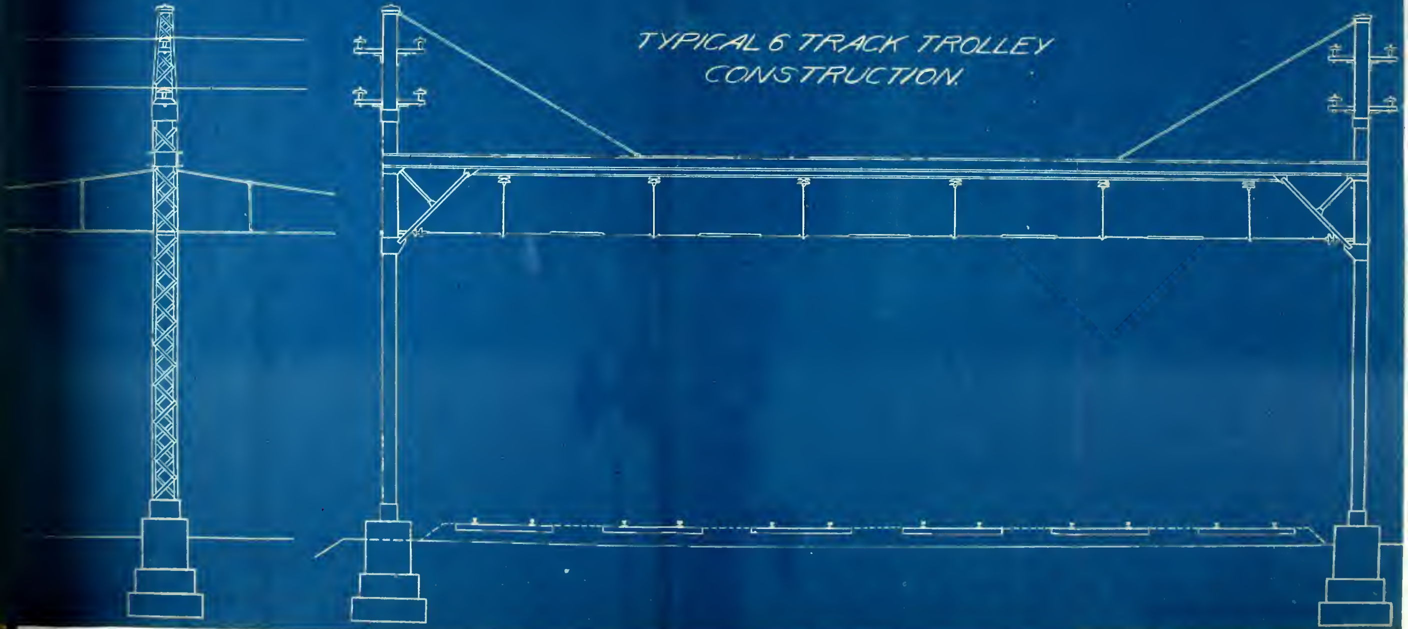


Electrification of the Illinois Central Railroad Terminal at Chicago, Ill.

BY

R. W. BROWN R. S. ELLG D. J. MALPEDE

Figure No. 46



TYPICAL 6 TRACK TROLLEY CONSTRUCTION.